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AUTHOR Bullock, Bob; And Others
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ABSTRACT

This minicourse was prepared for use with secondary physics students in the Dallas Independent School District and is one option in a physics program which provides for the selection of topics on the basis of student career needs and interests. This minicourse was aimed at helping the student relate the concepts of work, power, energy, momentum, and simple machines to sports. The minicourse was designed for independent student use with close teacher supervision and was developed as an ESEA Title III project. A rationale, behavioral objectives, student activities, and resource packages are included. Student activities and resource packages involve reviewing the playing details of seven sports, studying a few fundamentals of physics and related mathematics, analyzing some technical physics of seven sports, investigating student horsepower, and analyzing mechanical and anatomical machines. (GS)

CAREER ORIENTED PRE-TECHNICAL PHYSICS

The Physics of Sports

Minicourse

1974

PRELIMINARY EDITION

dallas independent school district

CAREER ORIENTED PRE-TECHNICAL PHYSICS

The Physics of Sports

Minicourse

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1974

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This Mini Course is a result of hard work, dedication, and a comprehensive program of testing and improvement by members of the staff, college professors, teachers, and others.

The Mini Course contains classroom activities designed for use in the regular teaching program in the Dallas Independent School District. Through Mini Course activities, students work independently with close teacher supervision and aid. This work is a fine example of the excellent efforts for which the Dallas Independent School District is known. May I commend all of those who had a part in designing, testing, and improving this Mini Course.

I commend it to your use.

Sincerely yours,

Nolan Estes

Nolan Estes
General Superintendent

mfs

CAREER ORIENTED PRE-TECHNICAL PHYSICS TITLE III ESEA PROJECT

Project Director:	Jesse M. Harris Assistant Director, Math-Science Dallas Independent School District
Project Editor:	Walt Elliott Physics Department California Polytechnic State University
Minicourse Authors:	Bob Bullock North Dallas High School
	Perry Oldham Lincoln High School
	Helen Shafer W. H. Adamson High School
	Hollis Tapp H. Grady Spruce High School
Physics Consultants:	Ben Doughty Physics Department East Texas State University
	Glenn Terrell Physics Department University of Texas at Arlington

CAREER ORIENTED PRE-TECHNICAL PHYSICS

THE PHYSICS OF SPORTS MINICOURSE

RATIONALE (What this minicourse is about):

This course is designed to help you relate the technical physics concepts of work, power, energy, momentum, and simple machines to sports. Whether you are an active athlete, a passive reader of *Sports Illustrated*, or one who enjoys sports telecasts you will profit from a knowledge of the physics of sports. For girls, this minicourse will prepare you to "rap" more knowledgeably about the physics of sports than most males you will meet.

You will have the fun of learning about the physics of vectors to illustrate such things as game plays, the flight of a football, or the curve of a baseball. You will learn that sports activities are beautiful demonstrations of Newton's three Laws of motion, that items of sports equipment are classic examples of simple machines, and that an athlete's body is essentially a complex anatomical machine (body machine) which must obey the laws of physics.

One unique thing about this minicourse is that you can perform some of the activities while watching a football game or other such game.

According to Harold Rosenthal, Public Relations Director of the American Football League, careers in sports should be considered not only in terms of being an active player but also in terms of sports-related careers. Such careers would include those of sports casters, sports writers, sports photographers, officials, coaches, scouts, public relations persons; and manufacturers and salespersons of sports products.

Many of us are aware of the current great figures in sports, but it may be of interest to consider a thumbnail sketch of some past greats.

1920's. Walter Hagen dominated professional golf, earned over a million dollars, and won consistently in golf's most prestigious tournaments, the U.S. and the British Open. Hagen's charisma and flair were legend, and he sometimes walked onto the course and played tournament golf in the evening clothes he had worn to the all-night party he had just left.
1920's. Lou Gehrig and Babe Ruth brought nightmares to big league baseball pitchers. The "Babe" set a home run record of 714, exceeded only by Henry Aaron in 1974! Gehrig's lifetime

batting average was slightly better than Ruth's, and the pitchers of their era faced these two power hitters in one-two sequence, since they played on the same team.

<u>1930's</u>. Knute Rockne of Notre Dame made himself "King of the Coaches". His teams lost only 2 of 122 games.

<u>1930's</u>. Mildred "Babe" Didrickson was a female who really "got it together" in track and field, tennis, billiards, swimming, basketball, diving, and golf. She set world's records in the 80-meter hurdles and the javelin throw, was the top professional golfer of her day, and won 8 of 10 events in the Los Angeles 1932 Olympic Games.

<u>1940's</u>. Jackie Robinson was one of the blacks who first broke the professional baseball "color line" in a big way, opening up other sports career opportunities to blacks. His finesse and ability were so extant that he was 1947's Rookie of the Year, and 1949's Most Valuable Player. This electrifying athlete captured the imagination of sports fans; admiration of his performance led ultimately to his election to baseball's Hall of Fame in 1962.

In addition to RATIONALE, this minicourse contains the following sections:

1) TERMINAL BEHAVIORAL OBJECTIVES. (Specific things you are expected to learn from the minicourse.)
2) ENABLING BEHAVIORAL OBJECTIVES. (Learning "steps" which will enable you to eventually reach the terminal behavioral objectives)
3) ACTIVITIES (Specific <u>things to do</u> to help you learn)
4) RESOURCE PACKAGES. (Instructions for carrying out the learning <u>Activities</u>, such as procedures, references, laboratory materials, etc.)
5) EVALUATION (Tests to help you learn and to determine whether or not you satisfactorily reach the terminal behavioral objectives):
   a) Self-test(s) with answers, to help you learn more.
   b) Final test, to measure your overall achievement.

TERMINAL BEHAVIORAL OBJECTIVES

Upon completion of this minicourse, you will demonstrate a knowledge of the physics of sports by:

1) picking five (5) modern sports out of a list of seven (7) and using these five to illustrate (by means of vector diagrams and the written word) certain basic principles of force and motion
2) analyzing the work, power, and energy associated with athletes' activities by means of diagrams, problem solutions, and written statements.
3) explaining in writing or orally how sports equipment and athletes' bodies relate to physics.

ENABLING BEHAVIORAL OBJECTIVE #1:

Pick five (5) of the seven (7) popular sports in this minicourse and use them to illustrate (orally or in writing) Newton's three laws of motion, conservation of linear momentum, and conservation of angular momentum.

ACTIVITY 1-1

Read Resource Package 1-1.

ACTIVITY 1-2

Examine some golf clubs. Make a chart and list each club under these categories: irons, woods, drivers, or putters. Next, write your impressions of these clubs in terms of comparative size, weight, and length.

ACTIVITY 1-3

In this case of iron clubs, record any relationship you can find between the <u>number</u> of the club and the <u>slant</u> of its face. What effect do you think the slant of an iron has on a ball trajectory (flight path)? The best way to find out is to hit some balls and record the observed differences in flight paths.

RESOURCE PACKAGE 1-1

"Seven Popular Sports"

ENABLING BEHAVIORAL OBJECTIVE #1

(See page 3 of this minicourse for statement of this objective.)

ACTIVITY 1-4

Look up the meaning of Par 3 holes, Par 4 holes, and Par 5 holes (Resource Package 1-2 may help you).

ACTIVITY 1-5

Read Resource Package 1-3.

ACTIVITY 1-6

Read Resource Package 1-4.

ACTIVITY 1-7

Spin a conical top and watch it come to rest as it loses energy because of frictional effects. Write a simple description of the types of equilibrium this activity illustrates (See Resource Package 1-4). Turn this explanation in to your teacher.

RESOURCE PACKAGE 1-2

"Selected Reading - Sports"

RESOURCE PACKAGE 1-3

"References - Physics"

RESOURCE PACKAGE 1-4

"The Dynamics of Sports"

ENABLING BEHAVIORAL OBJECTIVE #1

(See page 2 of this minicourse for statement of this objective.)

ACTIVITY 1-8

Carefully jump off a skateboard, or like kind of low-friction locomotor device (a skate, a wagon, etc.). Record the observed motions in terms of forces, moments, impulses, and momenta (See Resource Package 1-4). Turn this in to your teacher.

ACTIVITY 1-9

Your textbook may use a vector representation of balanced and unbalanced forces in the tug-of-war game. Explain tug-of-war forces in your own words in one or two paragraphs. Include sketches if you wish. Turn this in to your teacher.

ACTIVITY 1-10

Take test in Resource Package 1-5.

RESOURCE PACKAGE 1-5

"Self-test"

ACTIVITY 1-11

Check your answers using Resource Package 1-6.

RESOURCE PACKAGE 1-6

"Answers to Self-test"

ACTIVITY 1-12

Read Resource Package 1-7.

RESOURCE PACKAGE 1-7

"Some Technical Physics of Sports"

ENABLING BEHAVIORAL OBJECTIVE #1	ACTIVITY 1-13	
(See page 2 of this minicourse for statement of this objective.)	Make your own football play plan. It need not be professional! Keep it simple. Turn this in to your teacher.	
	ACTIVITY 1-14	RESOURCE PACKAGE 1-8
	Perform the investigative activities found in Resource Package 1-8. Prepare a simple written report of each investigation. Turn these reports in to your teacher.	"Investigating Some Physics of Sports"
	ACTIVITY 1-15	RESOURCE PACKAGE 1-9
	Read Resource Package 1-9. Perform the investigation and turn in a written report to your teacher.	"Circular Motion"
ENABLING BEHAVIORAL OBJECTIVE #2	ACTIVITY 2-1	RESOURCE PACKAGE 2-1
Use a selected sport, or the athlete in the selected sport, and orally identify a specific example of work and power.	Read Resource Package 2-1.	"Energy, Power, and Work"
	ACTIVITY 2-2	
	Read about energy, work, and power, using Resource Package 1-5 or other resources.	
	ACTIVITY 2-3	RESOURCE PACKAGE 2-2
	Complete Resource Package 2-2. Turn in your observations for evaluation.	"Student Power!"

ENABLING BEHAVIORAL OBJECTIVE #3	ACTIVITY 3-1	RESOURCE PACKAGE 3-1
Use a sport to illustrate various types of machines and their mechanical advantages.	Read Resource Package 3-1.	"Machines (Mechanical and Anatomical)"
	ACTIVITY 3-2	RESOURCE PACKAGE 3-2
	Complete Resource Package 3-2. Turn in your observations for evaluation.	"Wheel-and-Axle"
	ACTIVITY 4-1	RESOURCE PACKAGE 4-1
	Take the self-test in Resource Package 4-1 and check your answers using Resource Package 4-2.	"Self-Test"
		RESOURCE PACKAGE 4-2
		"Answers to Self-test"

RESOURCE PACKAGE 1-1

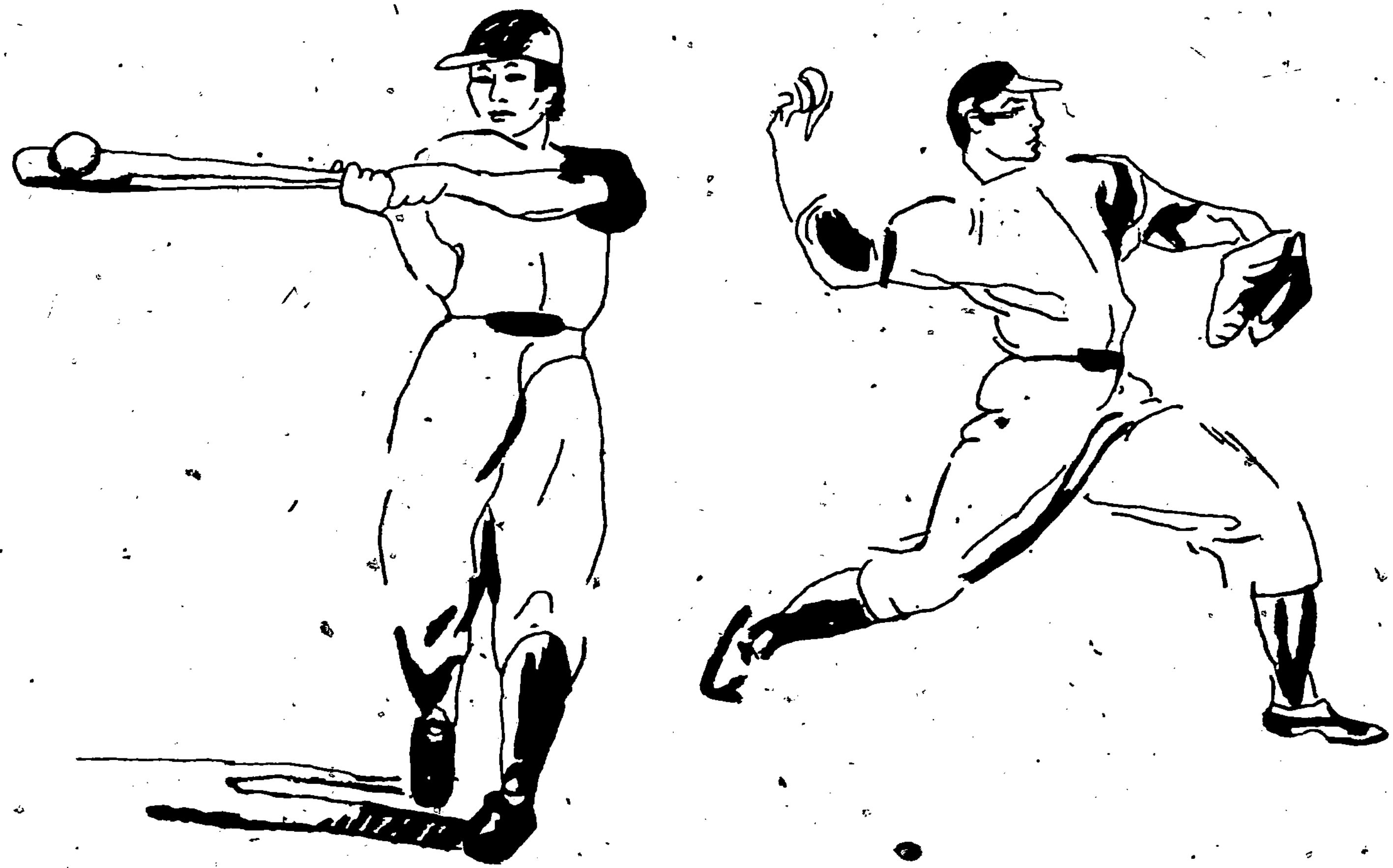
SEVEN POPULAR SPORTS

This section presents some technical details of the sports you will study in this minicourse and gives some idea of how each sport is played. These discussions are not intended to be complete or comprehensive, but they should provide sufficient explanations and descriptions for you to identify with each sport. The seven (7) sports considered are baseball, football, basketball, track and field, tennis, golf, and swimming.

Baseball. Baseball is a game played by two teams (sides) each consisting of nine (9) players. A game consists of nine innings played by each side. An inning is completed when three players on the batting side are out. If the score is a tie at the end of nine innings, play is continued until one side has scored more than the other in an equal number of innings.

The batter takes a position in the batter's box at the home plate, holding a round hardwood.* The pitcher standing in the pitcher's box delivers toward the batter's strike zone a ball weighing about 5 oz avoirdupois and measuring not less than 9 (and not more than 9¼) inches in circumference. The batter must strike at every delivered ball that pssses through the strike zone) over any portion of home plate not lower

*Metal bats are also available.

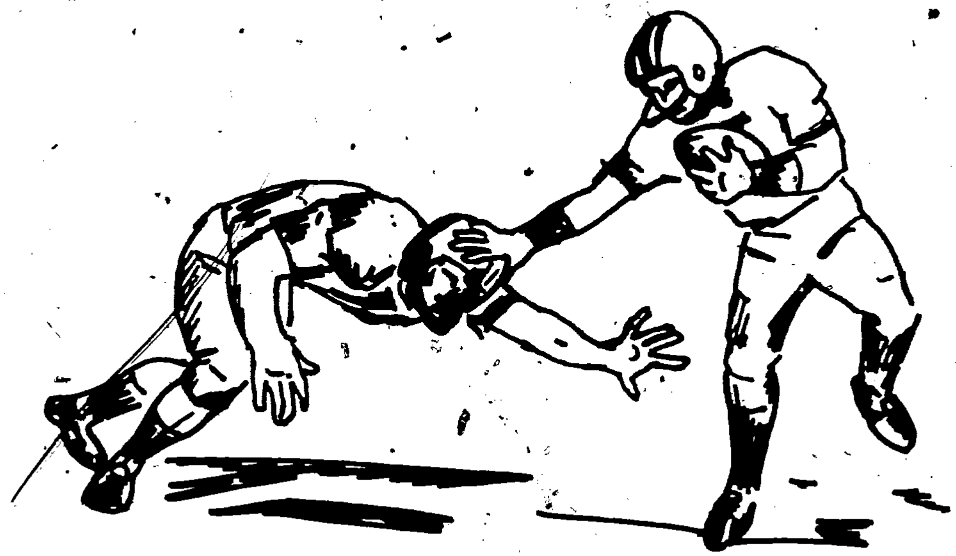


BATTER AND PITCHER

Fig. 1

than the knees, nor higher than the shoulders). After three failures to either strike at or to hit such a ball, the batter is out (provided the third ball is caught by the catcher before it touches the ground). If the catcher fails to catch the third such ball, the batter can still be put out by throwing the ball to a teammate on first base before the batter reaches there by running from the batter's box. The batter tries to hit the ball inside the foul lines in such a manner as to enable him/her to eventually make a complete circuit of the four bases, and thereby score a <u>run</u>. After making a successful hit (or after being "walked" to first base because four pitched balls were delivered outside the strike zone, or because of being struck by a pitched ball) the batter becomes a base runner. A runner scores a run after passing first, second, third, and home bases in succession without being put out. Fig. 1 illustrates a batter and pitcher in action.

<u>Football</u>. American football is a game in which the ball may be kicked, passed, or carried in a variety of ways during a timed contest between two teams of eleven men each. The team having ball possession is called the <u>offensive team</u>. The <u>defensive team</u> employs a number of strategies to claim ball possession and thereby take the offensive. Thus, the teams alternate on offense and defense. The defensive team can claim possession if it intercepts a pass, recovers a fumble, holds the offensive unit to less than a 10-yard gain in four plays (<u>downs</u>), etc.



TACKLER AND RUNNER
Fig. 2

Of the eleven players on each team, the middle man in the line is the center. On either side of him there is usually a guard, a tackle, and an end, in that order. In the backfield there are two halfbacks, a quarterback, and a fullback. The important elements of offensive and defensive football are the techniques of running, passing, kicking, catching, tackling, and blocking. Fig. 2 illustrates a defensive player attempting to tackle an offensive player (runner), who employs a "straight-arm" or "stiff-arm" tactic to ward off his would-be tackler.

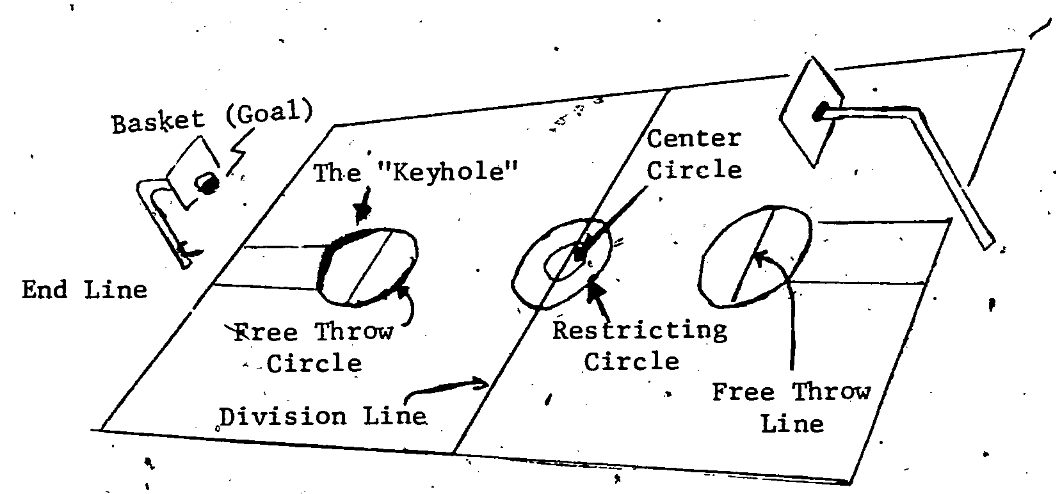
__Basketball__. Basketball is a popular international sport played between two teams of five players each. Playing positions may be designated as follows: two __forwards__, two __guards__, and a __center__.* Points are scored whenever a player makes a __field goal__ (two points) or a __free throw__ (one point). Free throws are awarded for certain fouls.

THE CENTER JUMP
Fig. 3

*High school rules for girl's basketball sometimes call for three guards and three forwards, and a different set of playing rules.

To start the game, two players face each other on opposite sides of the division line which bisects the center court circle. The referee tosses the ball into the air, higher than the extended arm of either jumper, and each player leaps upward and attempts to tap the ball to one of his four teammates. (See Fig.3) The team recovering the ball from the center jump is now playing offense and its goal is to put the ball into its offensive basket. To move the ball toward that basket the offensive team may employ the techniques of dribbling, passing, screening, and pivoting.

The offensive team keeps possession of the ball until they violate a rule, commit a foul, or score a basket. When a team is scored upon, it changes from defensive play to offensive play and is awarded the ball at the end line under its opponent's basket (goal). See Fig. 4 for an illustration of the game area (the court).



THE BASKETBALL COURT
Fig. 4

Track and Field. For centuries track and field events such as running, jumping, and throwing have been universally popular. This section will discuss briefly these track events: sprint, distance race, hurdle race, relay race. It will also consider these field events: high jump, pole vault, long jump, discus throw, and javelin throw.

Sprints. The most popular track events are the sprints; more athletes attempt these short races than any other track event. A must for sprinters is the ability to accelerate quickly and to maintain top speed over the entire distance run. The power developed is great in the sprint. The 440-yard and the 400-meter races are classified by many coaches as sprint races. It is not uncommon for a great quarter-miler to run the first 220 yards of his race in 22 seconds or less. Athletes in these races must combine rapid acceleration with endurance at top speeds.

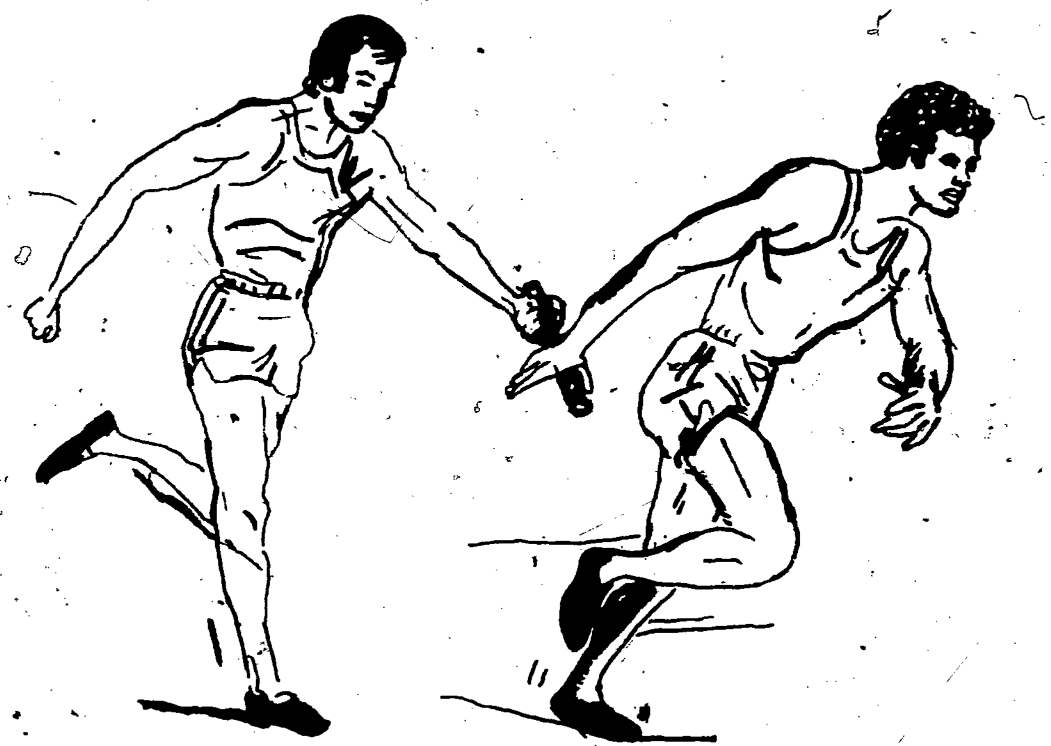
Middle distance events include all races over 440 yards, but less than two miles. The mile race is a middle distance event which is popular in the United States.

Distance running includes races from two miles to 10,000 meters ($\approx 6\frac{1}{4}$ mi). These races are becoming more popular in this country. Such races are included among the Olympic events and are often seen on telecasts from Europe.

THE HURDLES
Fig. 5

Hurdle races for men's Olympic and intercollegiate meets include the 120-yard and 440-yard events. Women's Olympic and intercollegiate meets include the 100-meter and the 400-meter hurdling events. Differences in hurdle heights exist (low hurdles and <u>high</u> hurdles, respectively) See Fig. 5.

Relay Races. In <u>relay races</u>, a rod (<u>baton</u>) is passes (<u>relayed</u>) from one member of a relay team to the next; each member runs a specific portion of the total race distance and then passes the baton. Sprint <u>relays</u> include the 400-, 880-, and 1760-yard (1 mi) races; and <u>distance relays</u> include the two-mile, four-mile, and medley races. A <u>medley</u> race is a relay race in which the members of the relay team run different distances. Fig. 6 illustrates a relay race.



PASSING THE BATON
Fig.6

Field Events. The field events consist of such jumping throwing, and vaulting activities as the long jump, the high jump, the pole vault, the shot put, the discus throw, the javelin throw, etc. See Figures 7, 8, and 9 for some illustrations of these events.

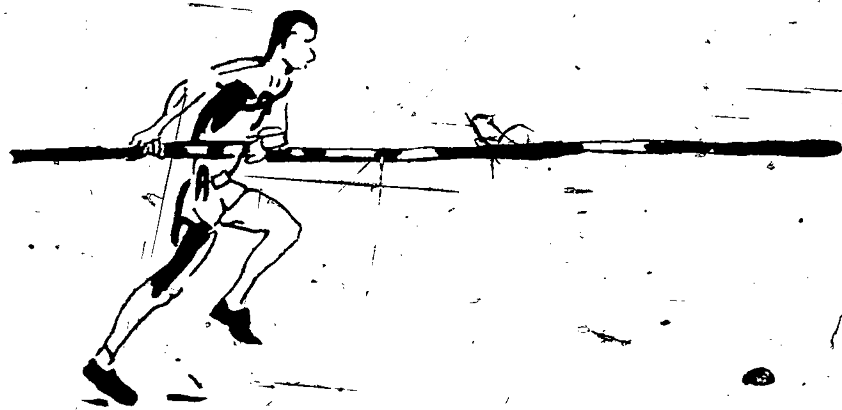
THE LONG JUMP
Fig. 7

The Shot-Put

SHOT-PUT AND
DISCUS THROW
Fig.8

The Discus Throw

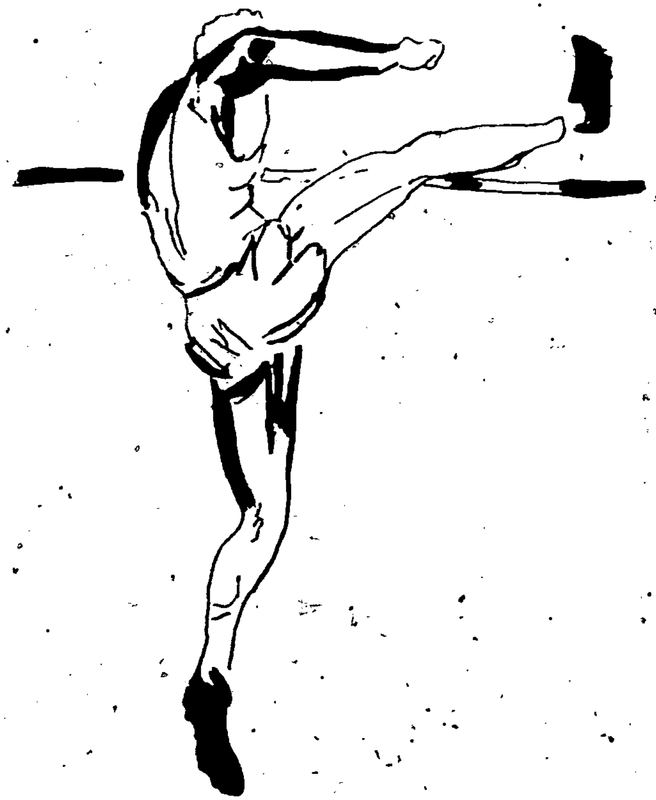
THE JAVELIN THROW
Fig. 8



The Running Approach

Clearing the Pole

POLE VAULT
Fig.9

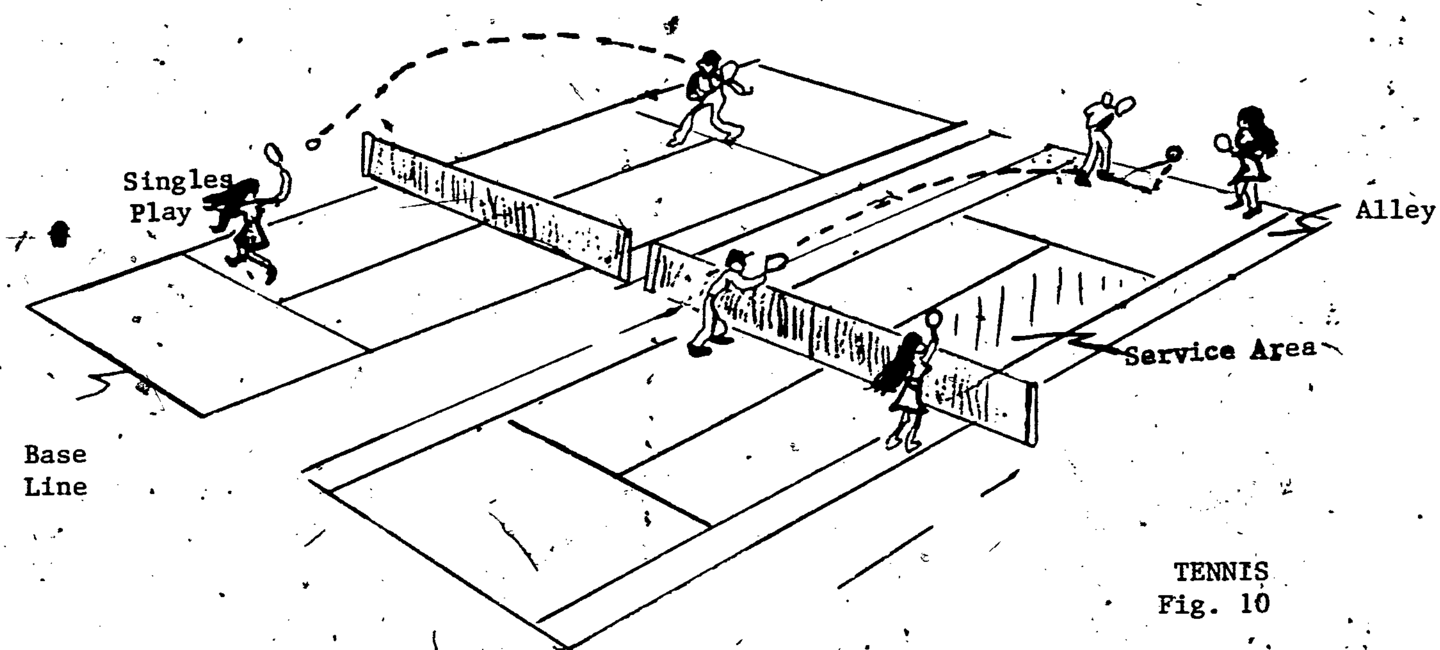


The Take-off

Clearing the Bar
(Western Roll Style)

HIGH JUMP
Fig.9

Tennis. Tennis is one of the fastest-growing sports for both men and women. Tennis players position themselves on opposite sides of a net and use rackets to hit a ball until one player misses the ball or hits the ball into the net or outside of the court. The ball cannot be returned if it has bounced more than once. Points are won if an opponent cannot keep the ball in play. After a certain number of points, a player has won a game. After a certain number of games, a player has won a set; and when a certain



TENNIS
Fig. 10

number of sets have been won, a player has won a match.

In doubles (two players on a team oppose another team of two players) the game is played according rules similar to those for singles. However, the doubles court is a little wider because of the addition of alleys. See Fig. 10.

Golf. Golf is a game which meets the recreational needs of a growing segment of the population. It is a game like tennis, in that people can enjoy it at almost any age. But unlike tennis, golf can be a "solo" game or can be played with one or more companions. The object of golf is to move a ball by hitting it with a club until it sinks into a hole (cup). The golf course has eighteen (18) holes and the player who makes a round of the course using the least number of hits (strokes) is the winner. You must start with the ball inside a designated area for each hole (called the tee) and then continue to hit the ball until you have stroked it into the cup for that hole. Your golf score is the sum of all the strokes you take on each hole for the 18 holes. Excellent golfers shoot in the 60's to 70's (60 to 70-plus strokes) for an 18-hole round.

Par is the number of strokes assigned to each hole for "faultless" play of that hole. Par is usually 70, 71, or 72 for 18 holes. When a golfer plays under par he is playing better than "faultless." Look up the meaning of Par 3 holes, Par 4 holes, and Par 5 holes.

Golfers use different clubs for different strokes. A variety of clubs is carried in the golf bag. This bag is frequently carried by a caddy. A part of golfing skill is the selection of the best club for a particular shot (hit). In general clubs are of two types: woods and irons. Woods are used for long distance shots, putters are used on the greens*, irons are used for short distances, and wedges are for special angle shots and sand traps.**

*Carefully tended and well-groomed grassy areas near the tees.
**Sand-filled areas scattered over the course.

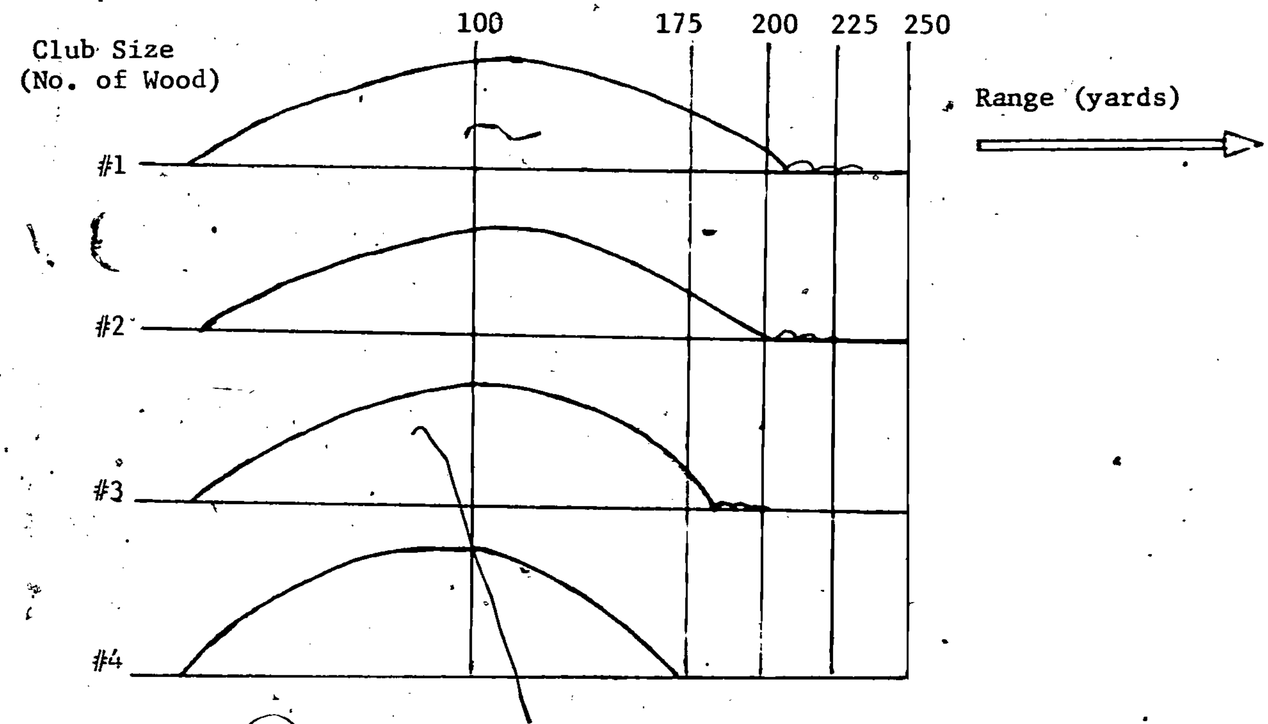
THE GOLF SWING*
Fig.11

*Courtesy of Ms. Kathy Whitworth, Past -president of Ladies Professional Golf Association and all-time highest money winner in the LPGA.

The golf <u>swing</u> (basic golf stroking action) is shown in Fig. 11. A golfer can change driving range by switching clubs without changing the basic swing. If the player needs a highly-peaked flight path to clear obstacles such as trees, simply switching clubs while <u>keeping the basic swing</u> can have the desired effect.

Different golf ball flight paths result from using different clubs because each club has a unique set of physical properties. The inertial mass, weight, flexibility, and face angle (slant of the face of club which actually contacts the ball) vary from one kind of club to the next. Each "kind" of club has a <u>number</u> assigned to it. The larger the number, the greater the <u>loft</u> or height of the ball for a given distance (See Fig. 12). In the charts and discussions which follow, you will learn something about club numbers and their relationships to ball trajectories. Fig. 12 also shows approximate ranges and trajectories (flight paths) for some <u>woods</u> for men golfers. Women's ranges will generally be less.

In Fig. 12, note that the drive off a tee with a #1 wood gives about the same trajectory height but a little more distance than with a #2 wood. For a higher arc and less distance such as over a tree obstacle, the #3 wood cauld be used. The #4 wood reaches an even earlier peak and gives the shortest distance of all. Remember that the basic golf swing remains the same for all these woods. It is the <u>physical properties of the</u> different <u>clubs</u> which account for the various trajectories.



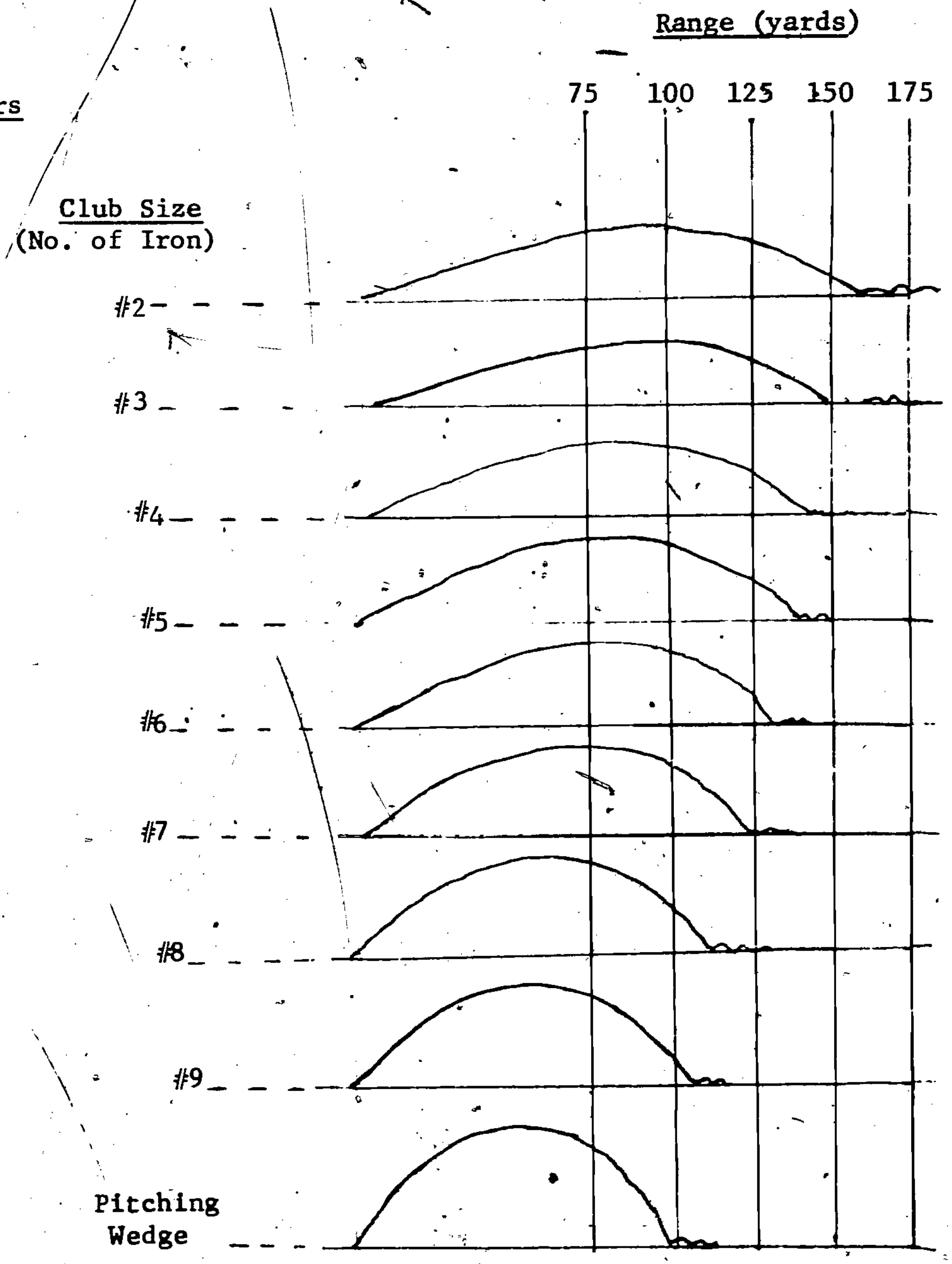
APPROXIMATE TRAJECTORIES AND RANGES FOR WOOD CLUBS (MALES)
Fig. 12

You will now learn something about irons (iron-faced clubs). When you examine these clubs you will notice that the larger the number, the greater the slant of the club's face. As with woods, the greater the number the greater the loft. The chart on the following page shows some approximate ranges and trajectories for various irons. Also, see Fig. 13

Approximate Ranges (yards) For Weak, Average, and Strong Players

Club Size (No. of Iron)	Weak	Average	Strong
1-iron	--	195	220
2-iron	155	185	195
3-iron	140	175	185
4-iron	125	165	175
5-iron	110	155	165
6-iron	90	145	155
7-iron	80	130	145
8-iron	70	120	135
9-iron	50	110	120
Pitching Wedge	--	100	100

RANGES AND TRAJECTORIES OF IRONS (MALES)



RANGES AND TRAJECTORIES OF IRONS (MALES)
Fig. 13

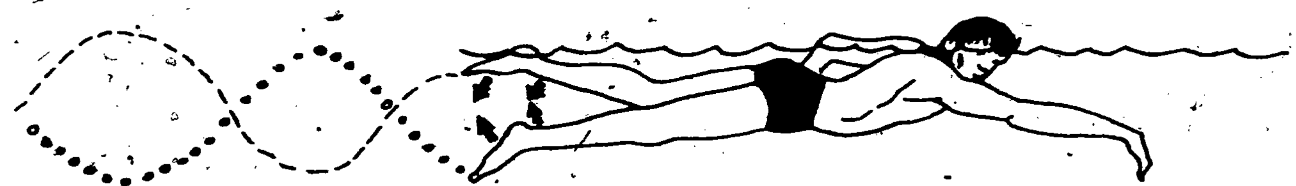
Fig. 14 presents some general range comparisons for males and females using the same clubs. Ranges are in yards.

CLUB	MEN	WOMEN
1 driver	210–250	150–180
2 wood	200–220	150–170
3 wood	190–210	145–160
4 wood	180–200	140–155
1 iron	180–200	150–180
2 iron	170–190	140–170
3 iron	160–180	130–160
4 iron	150–170	120–150
5 iron	140–160	110–140
6 iron	130–150	100–130
7 iron	120–140	80–120
8 iron	110–130	70–100
9 iron	100–120	60– 90
pitching wedge	90–110	50– 80
sand wedge	20–40	20– 40

SOME RANGE COMPARISONS
Fig. 14

Swimming. Swimming is a universal and ancient sport. It is one of the most beneficial sports and it is one which people can enjoy as active participants during an entire lifetime. There are several methods or styles of swimming. Four common methods (strokes) include the breast stroke, the side stroke, the overhand (crawl) stroke, and the back stroke. Fig. 15 illustrates the overhand crawl stroke. Action-reaction forces, Archimedes' buoyancy principle, and water friction are part of the physics of

swimming. These will be discussed later on in the minicourse.



THE OVERHAND CRAWL
Fig. 15

RESOURCE PACKAGE 1-2

SELECTED READING (SPORTS)

BOOKS

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6)* The Sports Illustrated Library: Baseball, Basketball, Ice Hockey, Football, Badminton, Fencing, Gaited Riding, Golf, Horseback Riding, The Shotgun, Shotgun Sports, Track and Field Events: Running Events, Skiing, Squash, Tennis, Wet-Fly Fishing, Swimming, Sailing, Diving, Boating, etc., J. B. Lippincott Company, New York, New York, 1956-1971.

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2) Sports Illustrated, Time, Inc., New York, New York.

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*These paperback books are inexpensive references of high quality, are easy to read, and are highly recommended as introductory materials.

**A highly-recommended reading; approximately 100 pages, with many pictures, make this little book interesting and useful.

RESOURCE PACKAGE 1-3

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1) Dull, Charles E., and others, Modern Physics, Holt Rinehart and Winston, Inc., New York, New York, 1963, pages 39-49.

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5)* Schaum, Daniel, Schaum's Outline Series, Theory and Problems of COLLEGE PHYSICS, McGraw-Hill, New York, New York, 1961.

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*Especially recommended for understanding problem-solving techniques in applied physics; contains 625 solved problems, with explanations.

RESOURCE PACKAGE 1-2

THE DYNAMICS OF SPORTS

To understand the physics of sports, it is important for you to review (or to learn for the first time) a few fundamentals of physics and related mathematics.

Vectors. In applied physics, a vector quantity is some physical property which has both size and direction. For example, weight, velocity, and force are vector quantities.

In technical physics, when we use numbers to describe the size, magnitude, or scale of some physical property, we use scalar numbers (scalars). Examples of scalar numbers used to describe physical scalar quantities are: 10 gallons (volume), 7 feet (length), 53^0 (temperature), 20 square miles (area), 7 miles per hour (speed), etc.

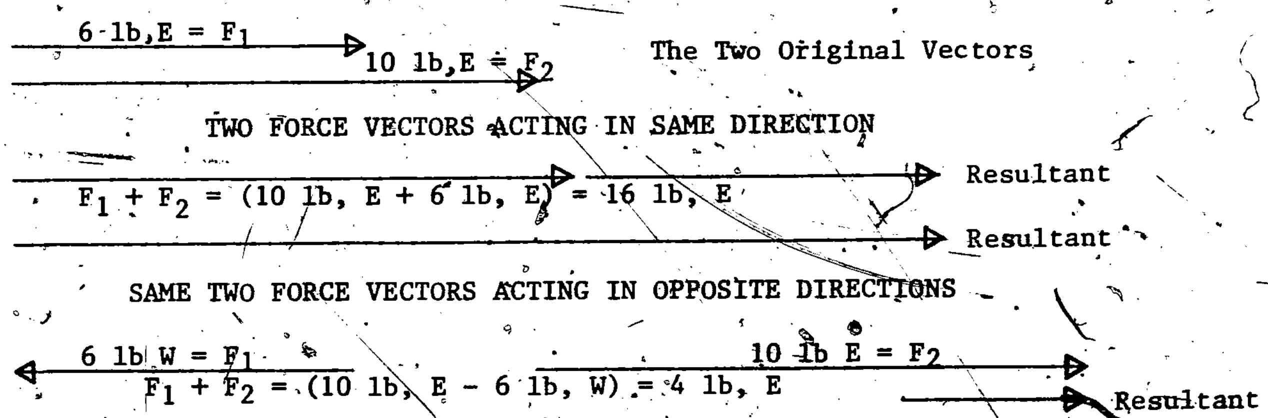
In technical physics, when we use numbers to describe simultaneously both the direction and the size (scale, or magnitude) of some physical property, we use vector numbers (vectors). Examples of vector numbers used to describe physical vector quantities are: velocity (7 miles per hour, north), weight (150 lb , downward), force (150 lb , horizontally), etc.

A two-dimensional vector number (vector numbers can have one or more dimensions) can be represented by a directed line segment (an arrow) whose length is scaled to show its size and whose direction is indicated by its arrowhead. For example, a force is a push or pull of definite size in a definite direction. Thus,

force is a physical vector quantity and can be represented mathematically (graphically) by a directed line segment (an arrow); and a small arrow is generally used to indicate that a mathematical symbol represents a vector quantity ($\vec{F}$ for force, for example).

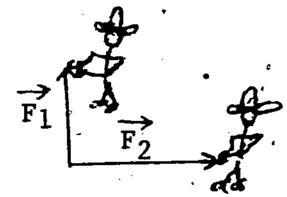
*<u>Vector Addition</u>. This is an <u>optional</u> section for those of you who are interested in some of the mathematical details of vector addition. Vector numbers can be added algebraically, graphically, and trigonometrically. It is strange but it is true that if physicists pick the proper kind of number to describe nature, then they can predict and explain natural activities quite completely through use of these numbers. For example, by using <u>vector numbers</u> to describe physical <u>vector quantities</u> we can tell how forces will combine and what effects will result from these combinations of forces. Below are some simple examples of such vector mathematics applications:

ADDING PARALLEL VECTORS
Fig.1

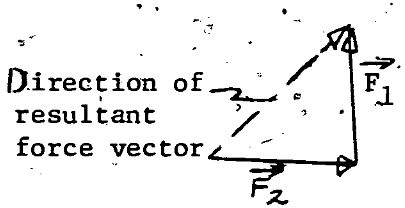


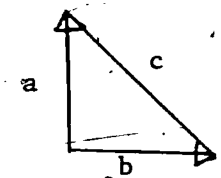
*Optional material. You don't need to know this to continue the course. If you can learn some of this, though, you'll have a much better idea of the physics of sports!

Consider two cowboys pulling equally on ropes positioned perpendicular (at right angles) to one another as shown:



Then the direction of the effective (resultant) force is some force $\vec{F}_r$ whose <u>direction</u> is midway between $\vec{F}_1$ and $\vec{F}_2$. Can you see that, $\vec{F}_1 + \vec{F}_2$ yields this <u>direction</u>? And the <u>size</u> of this resultant force can be found from the Pythagorean relationship, $c^2 = a^2 + b^2$:





size of $\vec{F}_1 = a$

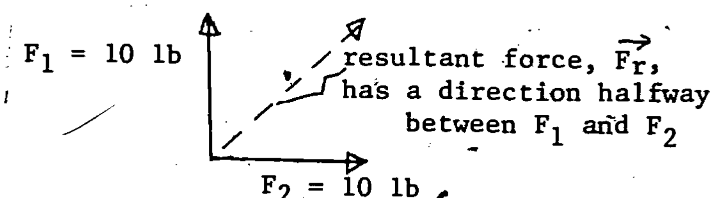
size of $\vec{F}_2 = b$

c = <u>size</u> of resultant force
(size of vector sum of $\vec{F}_1 + \vec{F}_2$)

Can you see that the <u>size</u> of the resultant vector is therefore,

$$c^2 = a^2 + b^2 = (F_1 \text{ size})^2 + (F_2 \text{ size})^2$$
$$c = \sqrt{a^2 + b^2} = \sqrt{(F_1 \text{ size})^2 + (F_2 \text{ size})^2}$$

For example, let each boy pull with a force of 10 lb; then:



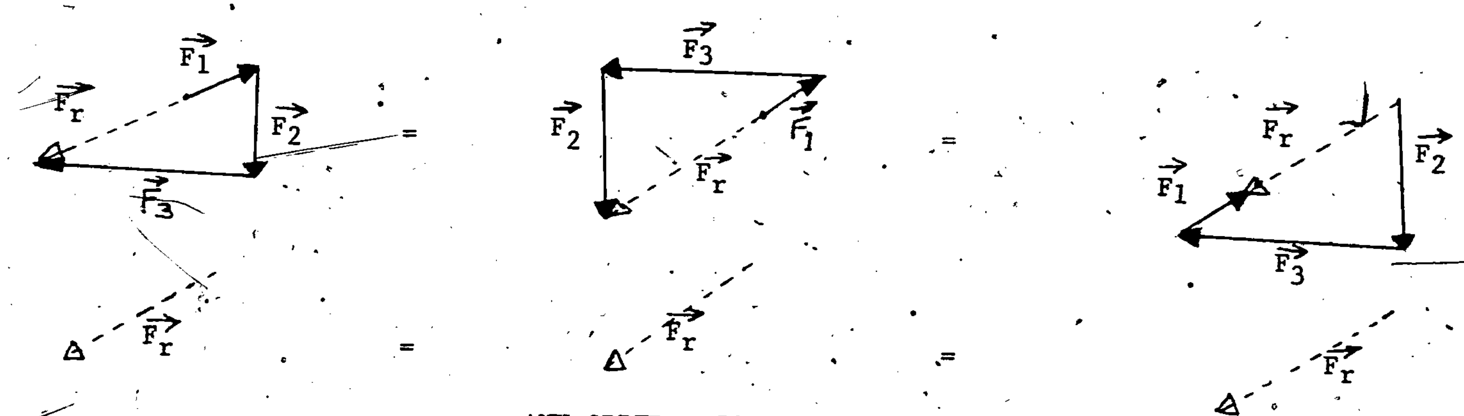
and $c^2 = a^2 + b^2$ becomes

$$F_r^2 = F_1^2 + F_2^2$$

$$F_r^{\,2} = (10\ \text{lb})^2 + (10\ \text{lb})^2$$
$$= 100\ \text{lb}^2 + 100\ \text{lb}^2$$
$$= 200\ \text{lb}^2$$
$$F_r = \sqrt{200\ \text{lb}^2}$$
$$\cong 14\ \text{lb}$$ (Caution: this Pythagorean solution is valid for vectors acting at right angles only.)

A useful and simple method for adding vector numbers graphically is the so-called "Circus Elephant Method," whereby a series of vector arrows are simply placed "trunk-to-tail". Care must be taken that each vector has correct relative length (or scale) and direction. The order with which these vectors are placed "trunk-to-tail" does not matter. Finally, a line drawn from the "tail" of the first vector to the "trunk" of the last vector will exactly (precisely) represent the resultant vector. An example follows:

$\vec{F}_1 + \vec{F}_2 + \vec{F}_3 \quad = \quad \vec{F}_1 + \vec{F}_3 + \vec{F}_2 \quad = \quad \vec{F}_2 + \vec{F}_3 + \vec{F}_1$

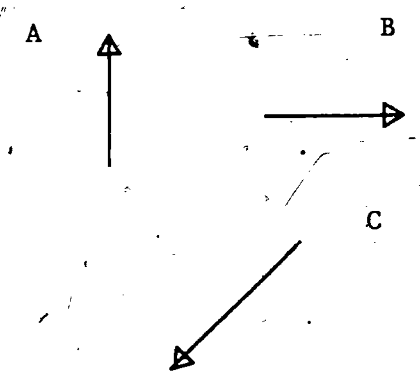


ANY ORDER - SAME SUM
Fig.2

Note that the <u>order</u> of adding vector numbers does not affect the sum (the resultant, $\vec{F}_r$). Note also that the arrows <u>must</u> be drawn to scale and <u>must</u> be kept always in their original directions. To subtract a vector (using the "Circus Elephant Method") <u>reverse</u> its direction and then proceed as in addition.

To give you some practice with the graphic method ("Circus Elephant Method"), work these exercises. Given vectors A, B, and C, whose lengths and orientations are as shown, find:

1) A + B	8) A - B - C
2) B + A	9) -A + B + C
3) A - B	10) -A - B + C
4) B - A	11) -A - B - C
5) A + B + C	12) A - C
6) A + B - C	13) B - C
7) A - B + C	14) C - B



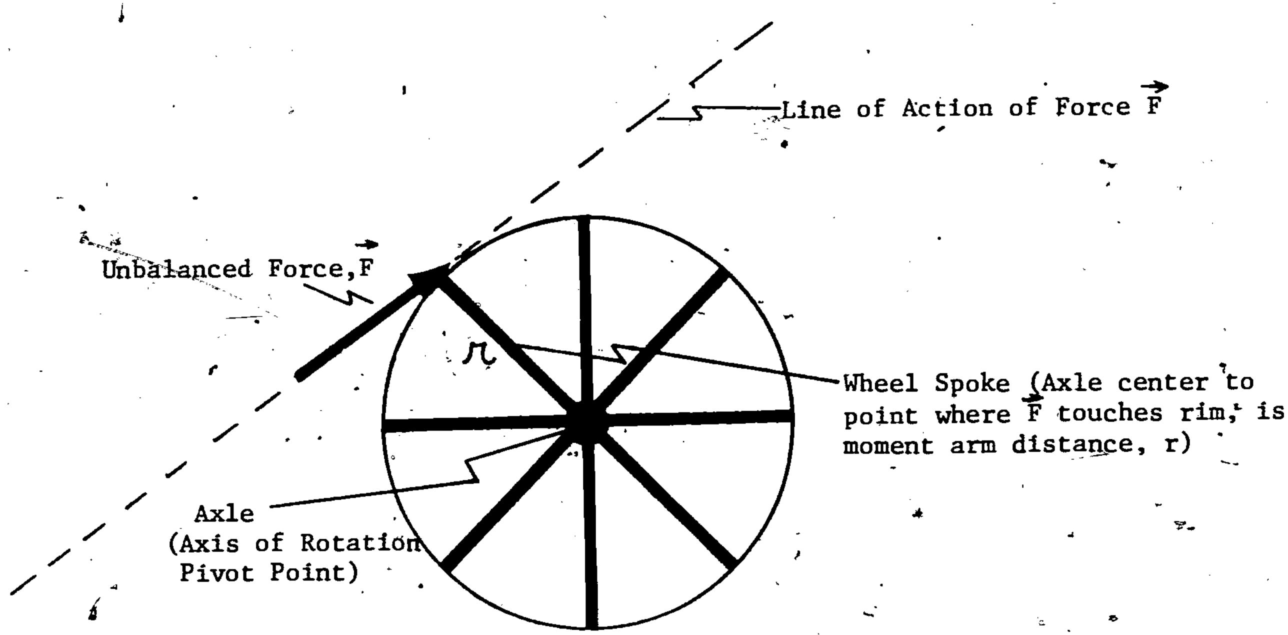
When you have finished, (or if you have difficulty) turn to page 51 for the answers.

<u>force</u>. For our purposes, a force is defined as a <u>push</u> or a <u>pull</u>.

Moment. In addition to pushing and pulling along some specific direction, a force may cause a body to twist or to rotate. The special name moment is given to this twist-producing effect. A moment is treated as a vector physical quantity because all twists (sometimes called vector moments, moments of force, or torques) have both a size (magnitude) and a direction (clockwise* or counterclockwise about an axis of rotation).

A moment (torque) can be thought of as having five components: 1) a force, 2) an axis of rotation, 3) a direction of rotation, 4) a moment (lever) arm, and 5) a magnitude (size). Look at the diagram below and try to relate it to these five (5) components. See Fig. 3.

*Clockwise is not a direction in the purest sense, but is applicable when the direction is obvious. If you are further interested, ask your teacher about the vector algebra of moments. (Or see the minicourse "Basic Machines - The Nuts And Bolts of Technical Physics."



FORCE ACTS ON WHEEL TO PRODUCE MOMENT
(M = f F)
Fig. 3

In this example, the axle center happens to be the axis of rotation; the direction of twist is clockwise; the perpendicular distance from the axis to the line of action of the force is the moment arm r; and the size of the moment is given by the equation M = r F (moment arm length multiplied by size of the force).

We can define the <u>vector</u> <u>moment</u> as the <u>product</u> of the <u>moment arm length</u> (perpendicular distance from rotational axis to force line-of-action) <u>and</u> ~~the~~ <u>force size</u>, with the <u>direction</u> of rotation indicated in some fashion.

Here is an example calculation, using the wheel diagrammed above. Assume the force size is 12 lb and the wheel radius in 1 ft. Then

M = (r) (F), plus indicated direction

= 20 lb (1 ft), clockwise

= 20 lb · ft, clockwise

Moments are especially important in the technical physics of "frisbees", football passes, baseball curves, bowling deliveries, hammer throws, arm wrestling, etc.

Friction. Friction is the name of a special kind of force which always opposes motion. Frictional forces act whenever the surfaces of moving objects come in contact. Friction can be useful. For example, it enables us to walk, to stop a car, to weave fabrics, to use nails to fasten boards together, etc. Friction can be a hindrance. For example, it requires lubrication of automobile engines, installation of powerful engines in speed boats, waxing of skis, etc.

Galileo's famous experiment, in which he reportedly dropped objects from the Leaning Tower of Pisa, was intended to show that all bodies fall at the same rate under the influence of gravity. Galileo's idea of falling bodies can be demonstrated by dropping a feather and a coin in a tube containing air. The feather, of course, falls slower than the coin because of air friction. However, when air is pumped out of the tube, the coin and feather fall together.

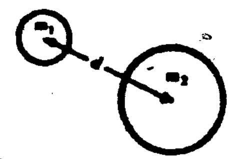
Weight. Weight is the name of a special kind of force (due to gravitational effects).

Weight and Mass. Weight and mass are two terms often confused by technical students. The law of gravitation states that any two objects at rest attract one another with a force directly proportional to the product of their mass properties and inversely proportional to the square of the distance separating their respective centers of mass. See Fig. 4. In equation form, Newton's law of gravitational force magnitude is:

$$F = G \frac{m_1 m_2}{d^2}$$

G = gravitational constant

$$F = G\frac{m_2 m_1}{d^2}$$



GRAVITY
Fig. 4

F is the size of the attractive force; d is the distance measured from the center of gravity of the first object to the center of gravity of the second object; G is a known physical constant; and m is the gravitational mass of an object (in a sense, it is a measure of the "quantity of matter" which makes up the object.)

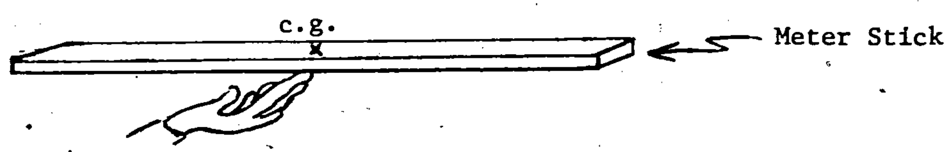
In the special case of earth, we use a special name for the force of gravitational attraction between the earth and all of its surface things. This special name is weight. In other words, weight is the name of a special force; it is a vector quantity. Weight is a measure of size and direction. The great football professional "Rosie" Greer, weighs "240 pounds, downward." His weight is a vector quantity; its size is 240 pounds and its direction is down, or towards the earth's center.

Mass is a scalar quantity. It has only a size property; no direction is associated with the mass of the earth. Remember that mass is not an object; it is not a thing! It is simply the measure of a property of a thing. The mass of a box is like its color or its size; mass is not the box itself

but only a description of one of the properties of the box. Mass is a scalar, just as size is a scalar.

Center of Gravity. In sports talk, center of gravity is a much-used phrase.

The weight of a body on earth refers to the gravitational attraction (force) between the matter which makes up the body and the matter which makes up the earth. The mass of any body is an indirect measure of the total amount of matter which makes up the body. The center of gravity (c.g.) of an object is the space point where one might consider all of its matter to be concentrated. For example, a meter stick balanced on a finger behaves as though all its matter were concentrated over the finger. "Center of mass" and "center of gravity" refer to that same space point where one can consider the matter of a body to be concentrated for convenience in solving many problems and in understanding many physical happenings.



BALANCED METER STICK

Motion. A simple definition of motion has these two components:

1) linear motion - moving from place to place
2) angular motion - turning about some axis

All motion involves both a scalar measure (size) and a vector measure (direction). For example:

1) Distance is a scalar term telling how far; displacement is a vector term telling how far and in what direction.

2) Speed is a scalar term telling how fast; velocity is a vector term telling how fast and in what direction.

3) Acceleration is a vector term telling how velocity changes. (The velocity change may be in size or in direction, or both.

Forces and moments (torques) are responsible for changes in motional states. All things resist being set into motion and resist any changes in their existing motions. These resistances to changes of motional states have the special names: inertial mass and inertial moment. A definition of each follows:

1) Inertial mass is resistance to change of linear motional state by any force.

2) Inertial moment is resistance to change of rotational motional state by any moment (torque).

Equilibrium. For a rigid object to be in equilibrium, no unbalanced force or unbalanced moment can act upon it. Balanced forces or moments simply means that all pushes, pulls, or twists acting upon the object are cancelled by opposing forces or moments. Consider a ball resting on the ground. The gravity force (weight) pulls it down with a force which is exactly cancelled by the ground reaction force pushing upward; this illustrates an equilibrium condition.

If an unbalanced force acts upon the object, a special kind of motional change occurs called linear

(straight line) acceleration; if an unbalanced moment acts upon the object, a special kind of motional change occurs called angular (rotational) acceleration.

In other words, whenever a rigid body is in an equilibrium state these three statements hold true:

1) If at rest, the body will remain at rest forever. It will never begin to move linearly and it will never begin to move angularly (spin).

2) If already moving linearly, the body will continue to move forever at constant linear speed and in the same direction.

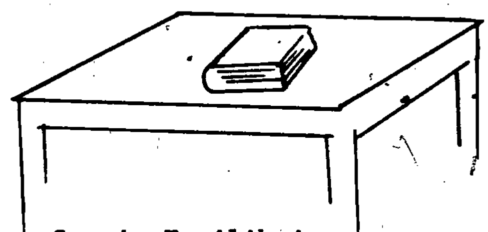
3) If already spinning, the body will continue to spin forever at constant angular speed and with its spin axis in the same direction.

The phrase static equilibrium implies (tells us) that an object must be at rest (neither spinning nor moving linearly) and that no unbalanced forces or moments are acting upon it. A bridge, for example, experiences many forces and moments resulting from automobiles, trucks, pedestrians, etc., but remains in static equilibrium (if it is to remain at all!). And the strong gymnast at the base of the "human pyramid" must be in static equilibrium.

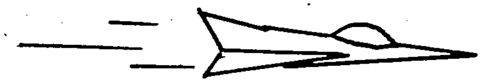
The phrase "dynamic equilibrium" implies that an object must be in motion (either spinning, moving linearly, or both) and that no unbalanced forces or moments are acting upon it. In a log-rolling contest (lumberjack event) the log spins rapidly at constant speed; log and athlete are in dynamic equilibrium and the lumberjack stays dry because the spinning log serves as a stable platform. If in dynamic equilibrium, the object (though moving) cannot speed up or slow down linearly or angularly,

and cannot change its spin orientation in space.

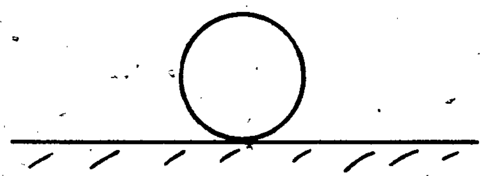
The diagrams below illustrate static and dynamic equilibrium:



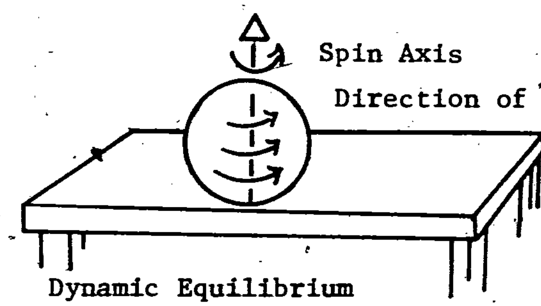
Static Equilibrium
(Book on table)



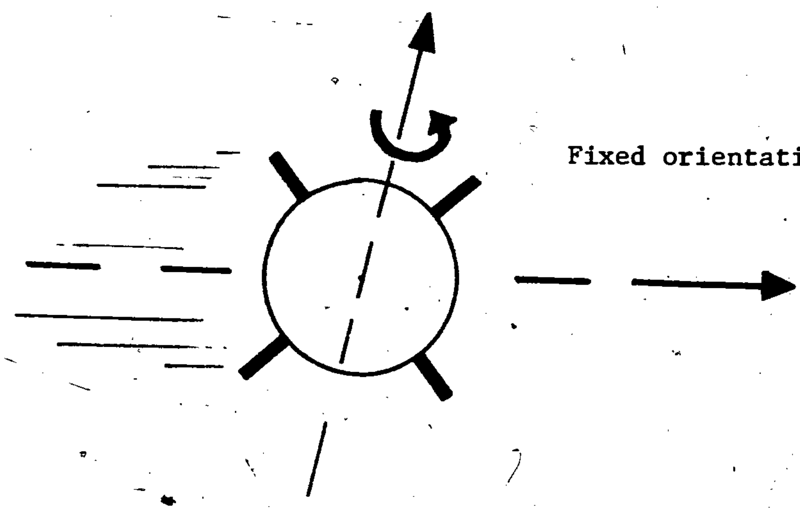
Dynamic Equilibrium
(Rocket ship at constant speed on a constant heading)



Static Equilibrium
(Ball at rest on floor)



Dynamic Equilibrium
(Ball spinning on table at constant angular velocity)



DYNAMIC EQUILIBRIUM

Spin-stabilized interstellar space ship spinning at 10 rpm and translating at 12,000 mph.

Newton's Laws of Motion. You will now try to catch up to some of the knowledge passed on to us by Sir Issac Newton over 300 years ago (in the 1660's!). His three famous laws of motion were as follows:

1) First Law (Equilibrium Law): Newton's First Law tells us that a body at rest tends to remain at rest and a body in motion tends to continue in motion in a straight line at constant speed unless it is acted upon by some unbalanced force. Remember that this property of matter which causes it to resist any change in its linear motional state (rest, or already existing motion) is called inertial mass. In other words, the mass of a body is a measure of its inertia. Newton's First Law implies also that if a body is spinning, it tends to continue spinning at constant speed and with constant direction (orientation) of its spin axis (Think of a gyroscope!) unless it is acted upon by some unbalanced moment (torque). This property of a body to resist any change in its angular motional state is called inertial moment.

2) <u>Second Law (Acceleration Law)</u>: This law tells us that the size of the linear acceleration of a body is directly proportional to the unbalanced (net) force acting upon it, is inversely proportional to the mass property of the body, and acts in the direction of the force. (Acceleration is a vector quantity!) Mathematically, we can write the <u>scalar</u> equation $a = \frac{F}{m}$ where $\underline{F}$ is the size of the net force, $\underline{m}$ is the mass property (property of resistance to linear acceleration) of the body, and a is the size of the acceleration. We can also write the <u>vector</u> equation $\vec{F} = m\,\vec{a}$, where the symbols have the same meaning and where we keep track of the <u>direction</u> of the net vector force, $\vec{F}$, and the vector linear acceleration, $\vec{a}$.

The second law implies also that the angular acceleration of a body is directly proportional to the unbalanced (net) moment acting upon it, is inversely proportional to the inertial moment property of the body, and is in the direction of the moment. (Angular acceleration behaves as a vector quantity!) Mathematically, we can write the scalar equation $\alpha = \frac{M}{I}$, where $\underline{M}$ is the size of the net amount (torque), $\underline{I}$ is the inertial moment property (rotation resistance property) of the body, and α is the size of the angular acceleration. We can also write a kind of <u>vector equation</u> $\vec{M} = I\vec{\alpha}$ where the symbols have the same meaning and where we keep track of the <u>direction</u> of the net vector moment, $\vec{M}$, and the vector angular acceleration, $\vec{\alpha}$.

Stop and think about Newton's First and Second Laws. Can you see that the First Law is a special case of the Second Law? Whenever no net forces or moments exist, a body cannot be accelerated! Mathematically, whenever $\vec{F}_{net} = 0$ and $\vec{M}_{net} = 0$, both $\underline{\vec{a}}$ and $\underline{\vec{\alpha}}$ must also equal zero; and this is PRECISELY THE FIRST LAW: no unbalanced or net forces (zero forces) and no unbalanced or net moments (zero moments) meet both conditions of equilibrium!

3) <u>Third Law (Action-Reaction Law)</u>: The Third Law tells us that for bodies in <u>contact</u>, every action is accompanied by an equal and opposite reaction. A linear example of the Third Law would be a person leaning against a rigid wall. The person exerts a force against the wall; the wall exerts an equal and opposite force against the person. Mathematically, we can write

$$F_{\text{person on the wall}} = F_{\text{wall on the person}}$$

A rotational example of the Third Law would be a person attempting to twist open a locked doorknob. The hand exerts a twist (moment) on the doorknob; the doorknob exerts an equal and opposite moment on the hand. Mathematically, we can write:

$$M_{\text{twist on knob}} = M_{\text{twist on hand}}$$

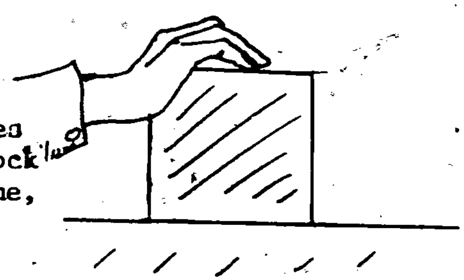
<u>Caution</u>: Some textbooks declare that "for every force, there exists an equal and opposite force." Do not accept this literally. "For every <u>contact</u> force (or torque) there exists an equal and opposite force (or torque)" is a truer statement.

It is important to remember that action-reaction forces (or torques) result from the interaction of <u>two different bodies</u>; therefore, action-reaction forces (or torques) <u>always</u> occur in pairs; but each force or each moment of a given pair can NEVER act on the <u>same</u> body.

<u>Impulse and Momentum</u>. An impulse occurs whenever a force ($\vec{F}$), or a moment ($\vec{M}$) is exerted upon a body for some interval of time (Δt). Mathematically, linear impulse (a vector) is expressible as the product of force and time interval ($\vec{F}\Delta t$); while angular impulse (a vector) is given by the product of moment and time interval ($\vec{M}\Delta t$). An example of each is shown below:

$\vec{F}$

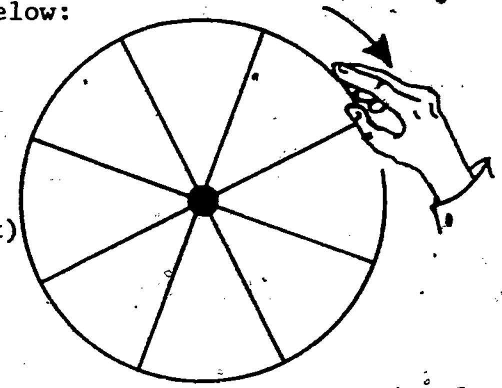
(Hand applies force to block for some time, Δt)



Linear Impulse = $\vec{F}\Delta t$

$\vec{M}$

(Hand applies moment to wheel for some time, Δt)



Angular Impulse = $\vec{M}$

Impulses accelerate objects; that is, impulses can <u>change</u> the velocities of objects. Associated with the velocity of an object is a measure of its motional condition called <u>momentum</u>; therefore <u>impulses cause changes in momenta</u>.

Since there are two kinds of general motion (linear and angular), with two kinds of associated <u>velocities</u> (linear and angular), and two kinds of associated <u>inertia properties</u> (inertial mass and inertial moment), you would be correct to suspect that there are <u>two kinds of momenta</u>:

1) <u>Linear momentum</u> is mathematically defined as $\vec{P} = mv$. This vector quantity has the SIZE of the product of inertial mass times <u>speed</u>, and has the DIRECTION of the linear velocity vector $\vec{v}$.

2) <u>Angular momentum</u> is mathematically defined as $\vec{L} = I\vec{\omega}$. This vector quantity has the SIZE of the product of inertial moment times angular <u>speed</u>, and has the DIRECTION of the angular velocity vector $\vec{\omega}$. <u>Omega</u> (ω) is the Greek letter commonly used to designate angular velocity and speed.

Let us compare the size of the linear momentum of an elephant running 10 mph to that of a professional fullback running the same speed. We will assume a 10-ton (20,000 lb) pachyderm (elephant) and a 200-lb athlete. The mass ratio of pachyderm to athlete is $\frac{20,000}{200}$ or 100:1 and their speeds are identical. Thus, from P = mv, you can see that the elephant has 100 times the momentum property of the fullback. Obviously, an elephant would make a great fullback! It would be 100 times more difficult to change its linear momentum (to stop it or to deflect it!)

Conservation of Momenta. Momentum is an important property of bodies in collision. Experiment shows that if we isolate two bodies (called a system*) and then let them collide, the linear and angular momenta of the two-body system before collision will be exactly equal to the momenta of the system after collision. Never in the entire history of physics has any scientist observed a violation of the Law of Conservation of Momenta (Momenta of system before interaction must be the same as momenta of system after interaction.)!

The Law of Conservation of Momentum can be written mathematically as

1) $\vec{P} = \vec{P}$ (Before, After) and 2) $\vec{L} = \vec{L}$ (Before, After)

where $\vec{P}$ is the linear momentum of the system; where $\vec{L}$ is the angular momentum of the system

Let's look at the mathematics of these two kinds of momenta once more.

1) Linear momentum. Mathematically, the product of a body's linear velocity and its inertial mass:

$$\vec{P} = m\vec{v}$$

2) Angular momentum. Mathematically, the product of a body's angular velocity and its inertial moment:

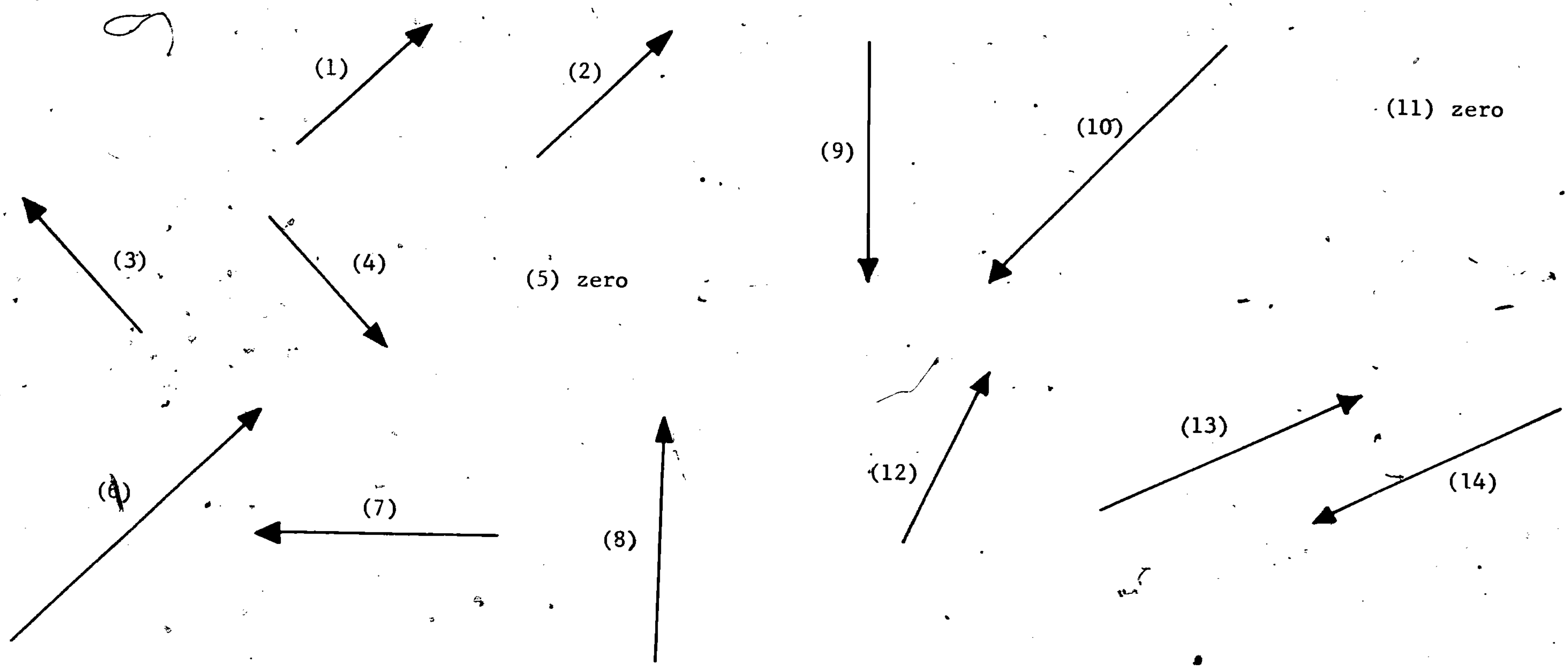
$$\vec{L} = I\vec{\omega}\ .$$

$\vec{L}$ is treated as a vector quantity.

*A system may be made up of any number of isolated bodies; it need not be restricted to two bodies. A familiar example of conservation of linear momentum of a system occurs when two objects of equal mass property collide head-on, one of them initially at rest; namely, when a cue ball strikes another ball head-on and that ball was at rest.

If you would like to see some applications of these momenta equations, refer to your text and to your instructor. A greater understanding of technical physics comes from working through problems. The Schaum's Outline Series, referenced earlier, is a good workbook.

ANSWERS. These are the graphic answers to the page 35 practice problems:

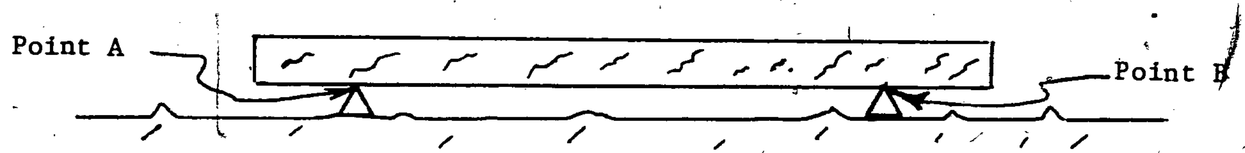


RESOURCE PACKAGE 1-5

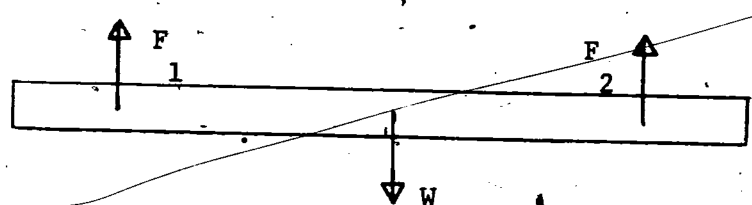
SELF-TEST

Write your answers on a separate sheet. Some questions require a word answer; others require alphabetical choices.

In the space diagram of this gymnasium floor support beam, the number of forces acting on the beam is (Answer 1.1): (a) 1 (b) 2 (c) 3 (d) 4 (e) not enough information given.



The beam is presented below in what physicists call a free-body diagram. In such a diagram, only forces acting on the body are shown. Forces the body exerts are never shown in a free-body diagram. Assume the beam is uniform throughout.



If the beam is at rest, Newton's First Law applies. Therefore, the magnitude of W down is (Answer 1.2): (a) equal to (b) less than (c) greater than (d) unrelated to the sum of F_1 and F_2. ALSO, the First Law requires that the moments clockwise about fulcrum A are (Answer 1.3): (a) equal to (b) less than (c) greater than (d) unrelated to the counter-clockwise moments about fulcrum A (where A and B represent the points of beam support).

The answer to 1.3, above, would be identical if the moments were summed about point B instead of point A. (Answer 1.4): (a) True (b) False (c) not enough information given.

This gymnasium floor beam analysis is based upon Newton's First Law, or, the Law of (Answer 1.5): (a) acceleration (b) equilibrium (c) action-reaction (d) energy conservation (e) none of these answers.

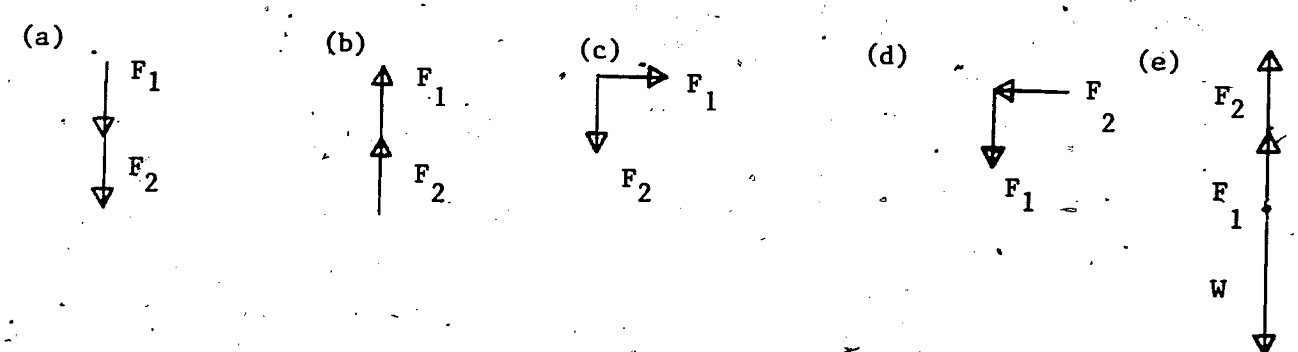
This law requires that the sum of the forces up must equal the sum of the forces down AND requires that the sum of the moments clockwise at any point on the rigid body must equal the sum of the counter-clockwise moments at that point:

(a) $F_{up} = F_{down}$

AND

(b) $M_c = M_{cc}$

These are the two necessary and sufficient conditions for (Answer 1.6): (a) acceleration (b) momentum conservation (c) action-reaction (d) energy conservation (e) equilibrium
Vector diagram (Answer 1.7): (a) (b) (c) (d) (e) best describes the forces:



Note: Do Not Write On These Pages, PLEASE. Use Your Answer Sheet.

An astronaut in gravity-free space decides to play "space-ball." He braces himself rigidly against the side of the spaceship and hurls a baseball into the vacuum surrounding his spacecraft.

The ball is initially at rest, so the hurling force acts first to overcome (Answer 2.1): i _ _ _ _ _ _. Because this is an unbalanced force on the ball, the ball is (Answer 2.2): a _ _ _ _ _ _ _ _ _ _ linearly in accordance with the formula (Answer 2.3): $\vec{F}$ = _ _.

The ball (Answer 2.4): (a) gains speed (b) has a constant speed (c) drops slightly (d) begins to slow down the instant it leaves his finger tips.

The astronaut's hurling force acts over a short time interval Δt. The product of $\vec{F}$ and Δt is the force-time relationship called vector (Answer 2.5): i _ _ _ _ _ _, and it results in a change in the vector linear momentum of the ball. The equation used here would be (Answer 2.6):

$$\vec{F}\,\Delta t = \_\_\_\_\_\_$$

Had the astronaut attempted to toss a curve ball by imparting spin with his wrist and finger tips then his unbalanced twisting force, or vector (Answer 2.7): m _ _ _ _ _, would have to overcome the ball's (Answer 2.8): i _ _ _ _ _ _ _ m _ _ _ _ _ property according to the equation (Answer 2.9): $\vec{M}$ = _ _ _.

Equations (2.3), above and (2.9) above, are the two complementary parts of Newton's (Answer 2.10): (a) 1st (b) 2nd (c) 3rd Law of Motion.

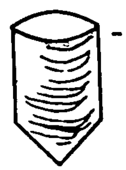
When the ball leaves the astronaut's hand (Remember, he is braced rigidly against the side of the spacecraft), (Answer 2.11): (a) astronaut (b) astronaut or spaceship (c) spaceship (d) astronaut and spaceship recoil(s) away from the ball. This is a case of (Answer 2.12): (a) momentum conservation (b) energy conservation (c) equilibrium. This is also a case of Newton's (Answer 2.13): (a) 1st (b) 2nd (c) 3rd Law of Motion, sometimes called the (Answer 2.14): ______________ Law.

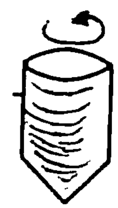
If the astronaut imparts spin (a curve) to the ball, the motional law for 2.13 and 2.14 above requires that the spaceship and astronaut must (Answer 2.15): (a) not rotate (b) rotate in the direction of ball rotation (c) rotate opposite the direction of ball rotation.

The athlete below has the lowest center of gravity and is therefore most stable in position (Answer 3.1): (a) (b) (c)

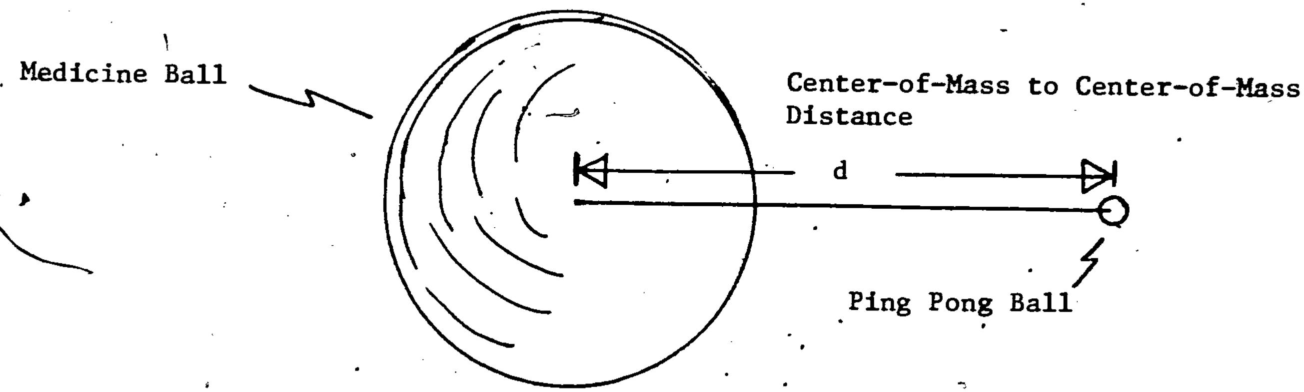
(a)  (b)  (c) 

Compared to top, a, the perfectly balanced spinning top, b, has a stability which is (Answer 3.2): (a) greater than (b) equal to (c) less than that for top, a.

Top a, Perfectly Balanced and Stationary 

Top b Perfectly Balanced and Spinning 

Consider a medicine ball, a ping pong ball, and the magnitude expression for Newton's Law of Universal Gravitation, $F = G \frac{m_1 m_2}{d^2}$



This Law implies that (Answer 4.1): (a) each ball (b) only the heavier ball exerts a gravitational force, and this force will (Answer 4.2): (a) increase (b) decrease by (Answer 4.3): (a) one-half (b) one-fourth (c) one-eighth if the separation distance, d, is doubled. If this distance is trebled (increased to 3d), the force is (Answer 4.4): (a) increased (b) decreased to (Answer 4.5): __________ times its value at separation distance, d. This is a very special distance measurement; it is the distance between the (Answer 4.6): c _ _ _ _ _ of mass (sometimes called (Answer 4.7): c _ _ _ _ _ of g_ _ _ _ _ _) of each ball.

If (Answer 4.8): (a) either ball (b) only the medicine ball (c) only the ping pong ball, (d) any of the answers (a), (b), or (c), is reduced in mass property by one-half, then the gravitational force will be (Answer 4.9): (a) four times larger (b) two times smaller (c) four times smaller, (d) two times larger.

Gravitational forces are (Answer 4.10): (a) sometimes repulsive (b) sometimes attractive (c) always repulsive (d) always attractive.

RESOURCE PACKAGE 1-6

ANSWERS TO SELF-TEST

1.1 (c), (3 forces)

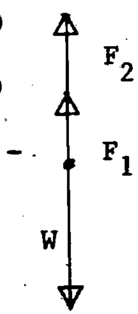
1.2 (a), (equal to)

1.3 (a), (equal to)

1.4 (b), (Equilibrium)

1.5 (e), (equilibrium)

1.6 (e) - - - - - - - - - -



1.7 (a), (True)

2.1 inertia

2.2 accelerated

2.3 $\vec{F} = m\vec{a}$ (should have an <u>arrow</u> over the <u>a</u> as shown)

2.4 (b), (has a constant speed)

2.5 impulse

2.6 $\vec{F}\,\Delta t = m\,\Delta\vec{v}$

2.7 moment

2.8 inertial moment

2.9 $\vec{M} = I\vec{\alpha}$

2.10	(b), (2nd Law)
2.11	(d), (astronaut and spaceship)
2.12	(a), (linear momentum conservation)
2.13	(c), (3rd Law)
2.14	Action-Reaction
2.15	(c), (rotate opposite to the direction of the ball rotation)
3.1	(a) (Note: his c.g. is lower than in (b) or in (c); and his support base is braoder:
3.2	(a), (greater than)
4.1	(a), (each ball)
4.2	(b), (decrease)
4.3	(b), (one-fourth)
4.4	(a), (decreased)
4.5	one-ninth (1/9)
4.6	centers
4.7	center of gravity
4.8	(a), (either ball)

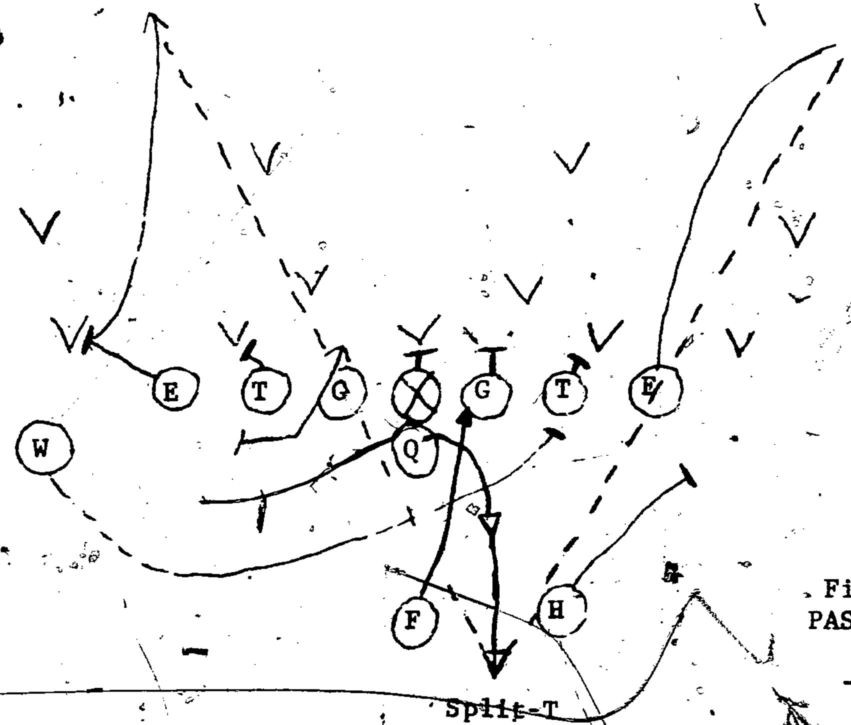
4.9	(b), (two times smaller)
4.10	(d), (always attractive)

RESOURCE PACKAGE 1-7

SOME TECHNICAL PHYSICS OF SPORTS

In this activity you will study some technical physics of the following popular sports: baseball, football, basketball, track and field events, tennis, golf, and swimming.

Vector Diagrams. Vector diagrams are used in making play plans for many sports. Examples include the play plans for football, basketball, and baseball. Figure 1 is a football play plan for a forward pass from a faked inside drive off a split-T formation.



Key

V - Defensive team
O - Offensive team
- - - - Pass paths
→ - Player paths
⊣ - Block
E - End
G - Guard
T - Tackle
H - Halfback
W - Halfback in wingback position
⊗ - Center
Q - Quarterback
F - Fullback

Fig. 1
PASS PLAY

Notice that the vectors (arrows) in Figure 1 give general direction and give some indication of distance players move; but these vectors are not precisely defined, as they are in physics where a vector quantity is always clearly defined in size and direction. Let us review the play plan and you can see why these are only "approximate" vectors. In Figure 1, the QB <u>fades back</u> slightly to the right, faking first to the FB who slams (<u>fakes</u>) inside his RG, and then faking to the LHB who was in motion before the <u>ball snap</u> from C. to the QB. If the QB is <u>shifty</u> enough, he can double-fake to this LHB to create additional confusion in the <u>defensive unit</u> ranks. It is important that both the FB and LHB carry out hard fakes accompanied by hard blocks from their teammates, to give every indication of a run! The RHB <u>checks</u> the defensive LE; the RE gives a momentary block to an opposing lineman and then goes downfield and to the right on the pre-set <u>pass pattern</u>.

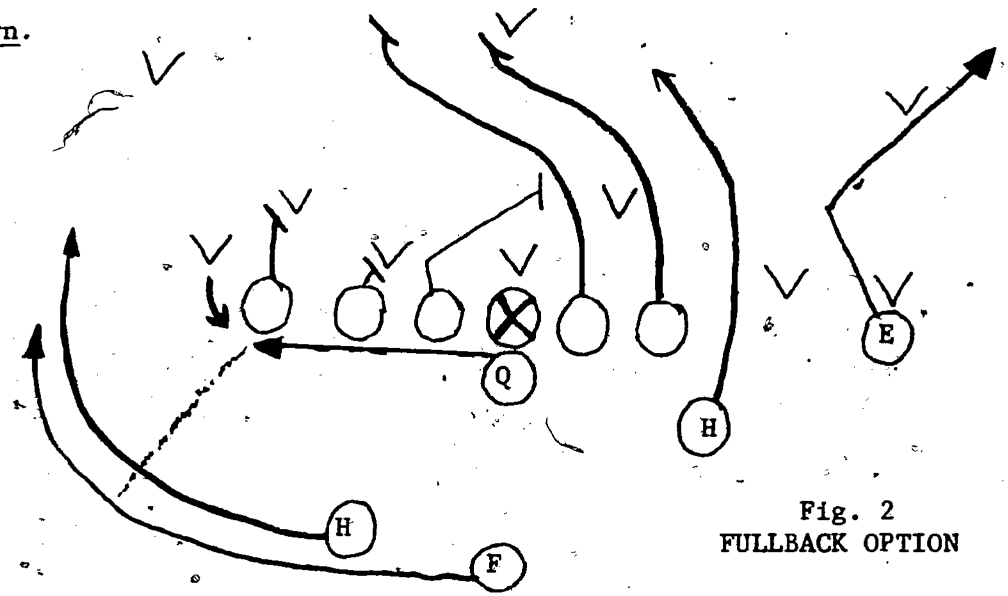


Fig. 2
FULLBACK OPTION

Let's look at another example of a football play diagram; namely, the fullback <u>option</u> play shown in Figure 2 on the previous page. Notice that the vectors in Fig. 2, as in Fig. 1, give only approximate direction and magnitude, unlike the precise vector applications of science. After the snap from C (keyed as ⊗) the QB <u>shuttles</u> parallel to his line. If the defense penetrates on that side, the QB fakes a pitch out to his FB or HB and <u>scrambles</u> downfield on his own. If the defensive line is not penetrated, the QB may pitch out to the FB (as diagrammed) just before the defensive end (<u>corner man</u>) tackles him. The LHB goes for the outside leg of that <u>outside</u> defensive corner man, trying to pin him to the <u>inside</u> and thus <u>break the FB loose</u> for a gain. This is an option play because the QB can either keep the ball or <u>opt</u> to pitch out to the FB.

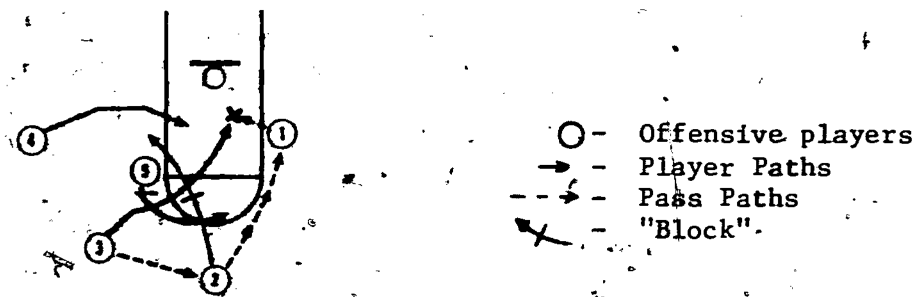


Fig. 3
BASKETBALL PLAY PLAN

The vectors in Fig. 3 (above) show a <u>basketball play plan</u>, using what is called a <u>shuffle offense</u>. Again, <u>such vector applications show only general movement of the players</u>. It would be an unnecessarily complicated task to show player movements by the vector addition and vector composition methods of technical physics.

The preceding applications of vectors to play diagrams was a very loose, non-scientific, imprecise usage as compared to technical physics applications. Here is an example from technical physics. A sportsman decides to sail across a stream (See diagram.) His boat sails 4 mph in still water, and the stream flows 3 mph. With what velocity will he move across the stream? We use the Pythagorean relationship between the lengths of sides of a right triangle to find the resultant speed, and we use vector diagrams to find the resultant direction.

(1) $c^2 = a^2 + b^2$

$= (4 \text{ mph})^2 + (3 \text{ mph})^2$

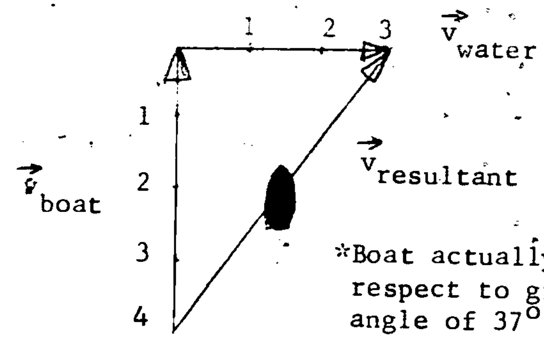
$= 16 \text{ mph}^2 + 9 \text{ mph}^2$

$= 25 \text{ mph}^2$

$c = \sqrt{a^2 + b^2}$

$= \sqrt{25 \text{ mph}^2}$

$= 5 \text{ mph}$



(2)

*Boat actually moves 5 mph with respect to ground, and at an angle of 37° from its bow heading.

The boat's velocity (with respect to the earth) is 5 mph in the direction shown.* Velocity implies <u>both</u> a speed and a direction.

Force and Motion. Naturally, all sports involve force and motion. To understand force and motion in sports you study the meaning of such terms as speed, velocity, acceleration, moment, inertia, impulse, and momentum.

Inertia. About three hundred years ago, Sir Isaac Newton, the English scientist, formulated some basic descriptions (laws) of motion. One of these laws (First Law) states that an object at rest tends to remain at rest unless some force causes a change; and, a moving object tends to continue moving unless some force causes a change. A force is defined as either a push or a pull; and a moment is defined as a clockwise or counter-clockwise twist. For example, an object which is not moving will remain that way forever unless it is moved by muscle force, gravity force, wind force, electric force, or some other force. When you pull on a heavy object, the object starts moving slowly at first. This is because the object resists being moved. This tendency of all objects to resist change in motional condition is called inertia. There are two kinds of inertia: (1) inertial mass is the name given to resistnace to change of linear motion; and (2) inertial moment is the name given to resistance to change of rotational motion.

Inertia is related to Newton's First Law (sometimes called "Inertial Law" or "Equilibrium Law") in the sense that when all forces or moments (torques) acting upon a body cancel out one another, the motional state of the body must remain unchanged. Inertia properties are easy to identify in athletics. Here are some examples:

a) At an Olympic track meet a sprinter must start from rest. Her body tends to remain at rest. Therefore, her muscles must work very hard to overcome the inertial mass property as she moves from the starting blocks to sprint speed.

b) A baseball player at bat must be well into his swing before the pitcher's fast ball reaches him. It takes time to overcome the inertia of the bat and of his body itself. If he swings too late to hit a fast ball, he has a strike called on him.

c) When a swimmer makes a high dive into the water at a "flat" angle, she can hurt herself. One reason for such an injury is the inertial property of the water, which resists being shoved rapidly out of its rest position by the diver's body.

d) The race car driver, when the car's brakes are applied, will continue to move forward at the same speed that the car was traveling before he suddenly applied the brakes to avoid a pile-up. Only his safety harness can hold him to the slowing race car. He understands well the slogan, "Buckle up and live".

In sports the players, the balls, the bats, the clubs, the rackets, etc., can move fast; so it can take a great deal of force to stop or to change their directions of motion. The inertial mass property of all things, you see, plays a big role in athletic games. Here are some additional examples:

a) A baseball player sprinting to first base cannot stop instantly when he reaches the base because of his inertial mass and consequent linear momentum ($m\vec{v}$). This is why baseball rules allow a runner to run past first base without being tagged out (provided he touches the base as he passes).

b) A batter sometimes starts to swing at a pitched ball and, too late, realizes it is not in the strike zone. She cannot stop her swing easily because of the inertial mass properties of her muscles and moving bat. On the other hand, if a batter swings hard at a fast ball and misses the ball completely her inertial moment, plus the bat's inertial moment, may swing her completely around.

c) A football player running with the ball suddenly changes direction to escape a pursuing tackler. The inertia and consequent momentum of the tackler cause him to continue moving in the same direction of pursuit he had before the runner charged off on a new course.

Impulse and Momenta. Earlier in this minicourse you were introduced to the mathematical formulations of vector impulse and vector momenta. Repeated on the following page are those relationships:

Linear Case

Linear impulse = Change in linear momentum

$$\vec{F}(\Delta t) = m(\Delta \vec{v})$$

(Applied force)(Time force acts) = (Inertial mass)(Change in linear velocity)

Angular Case

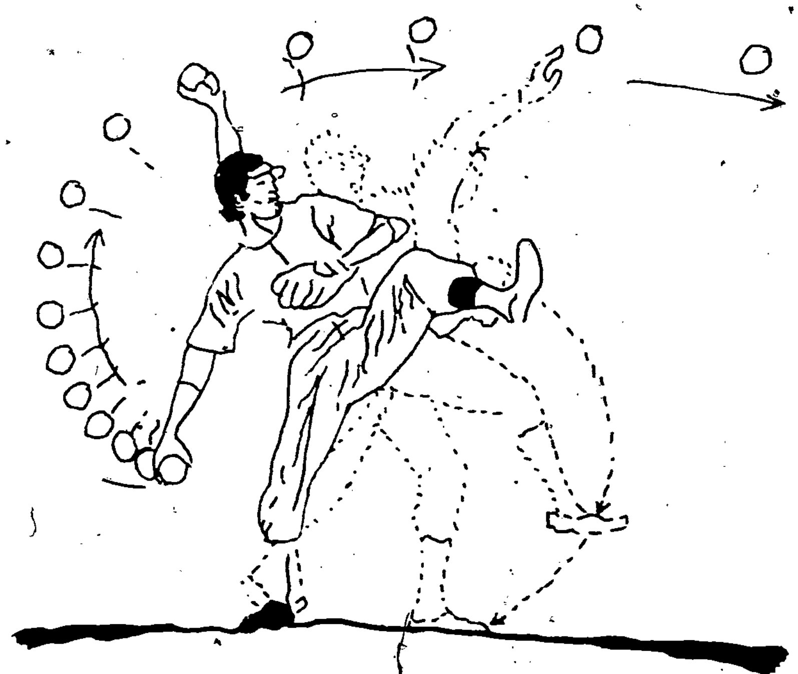
Angular impulse = Change in angular momentum

$$\vec{M}(\Delta t) = I(\Delta \vec{\omega})$$

(Applied moment)(Time moment acts) = (Inertial moment)(Change in angular velocity)

The symbol delta (Δ) stands for a measured specific "chunk" of any physical quantity such as time interval, distance interval, quantity of matter, etc.

From these impulse-momenta equations, can you see that the <u>duration</u> of a force (or moment) <u>affects motion</u>? For example, the longer a force acts on an object to change its speed the greater the speed change will be. Suppose a male player is preparing to throw a ball. At the instant he starts his delivery his arm is held low and behind; the ball is virtually at rest. As the pitcher overcomes inertia, the ball in his hand moves faster and faster. This change of velocity is called <u>acceleration</u>. The longer he applies a driving force to the ball before he releases it, the faster the ball will move. (See Figure 4 on the next page.)



Duration of a force affects motion (1/100 sec between each position)

Fig. 4
PITCHING

In golf and tennis good players continue their swings as long as possible. Baseball batters also take long swings. This continuation of swing after contact is the long-swing action called follow-through. Physics-wise, follow-through results in the impulsive force acting over a longer time interval; sports-wise, follow-through can transfer more momentum or energy and can also impart "touch" or control to the missile.

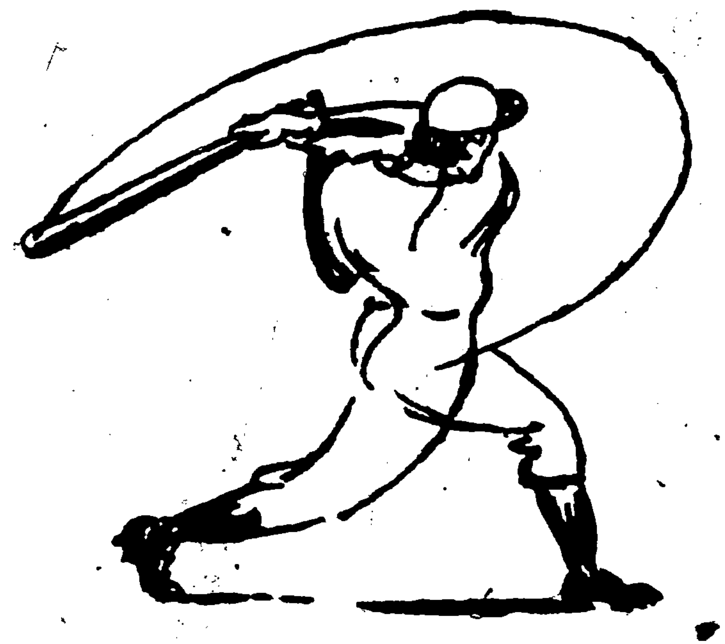


Fig. 5
BATTING IMPULSE (Follow-through)

Figure 5 illustrates the follow-through in baseball batting. The bat force changes the momenta of the ball. Since momenta are <u>vector</u> quantities this means that the speed, the direction, and the spin of the ball can be changed. For an illustration of follow-through in the shot-put event, see Figure 6 on the next page. Notice that in the shot-put the athlete starts low and follows through so as to apply the impulsive force as long as possible, and thereby to impart as much momentum as possible to the shot.

Fig. 6

SHOT-PUT IMPULSE (FOLLOW-THROUGH)

This same principle of follow-through is used in reverse when a force slows down an object. When a baseball player catches a fast ball, he draws the glove slightly toward himself as the ball strikes his glove. This technique increases the time that the slowing down force of his glove can act. The

result is that the ball does not strike the glove with as strong an impulsive force. A <u>smaller</u> "slowing force" acts over a <u>longer</u> time interval to produce the same slowing-down effect of a larger force over a shorter time interval. This technique effectively reduces the possibility of the ball's bouncing out of the glove and also reduces the sting of the hand by the ball.

Notice that when a football player catches the ball, his body "gives" with the ball. This provides an extra fraction of a second, which helps to slow the speed of the ball and prevent its bouncing out of his hands.

<u>More on Momenta</u>. Recall that linear momentum is expressed as $m\vec{v}$ and angular momentum as $I\vec{\omega}$. Therefore, the faster a football player runs the greater will be his impact (momentum) if he strikes another player. Also, the heavier the player is, the greater will be his impact for any given speed. A heavier player has more body matter, and therefore has a greater inertial mass property associated with him. A lightweight object, such as a bullet, can have much "hitting" effect (momentum) because it is fast; but a heavyweight object, such as a truck, can exert the same "hitting" effect (momentum) even if it is moving slowly because it has such a great mass.

Figure 7 (See next page.) illustrates linear momentum in football. The 200-pound player moving at 3 miles per hour has as much linear momentum as the 100-pound player moving at 6 miles per hour.

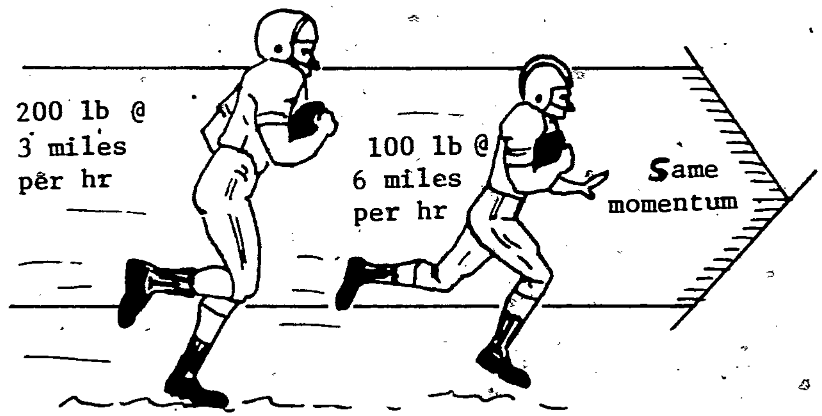


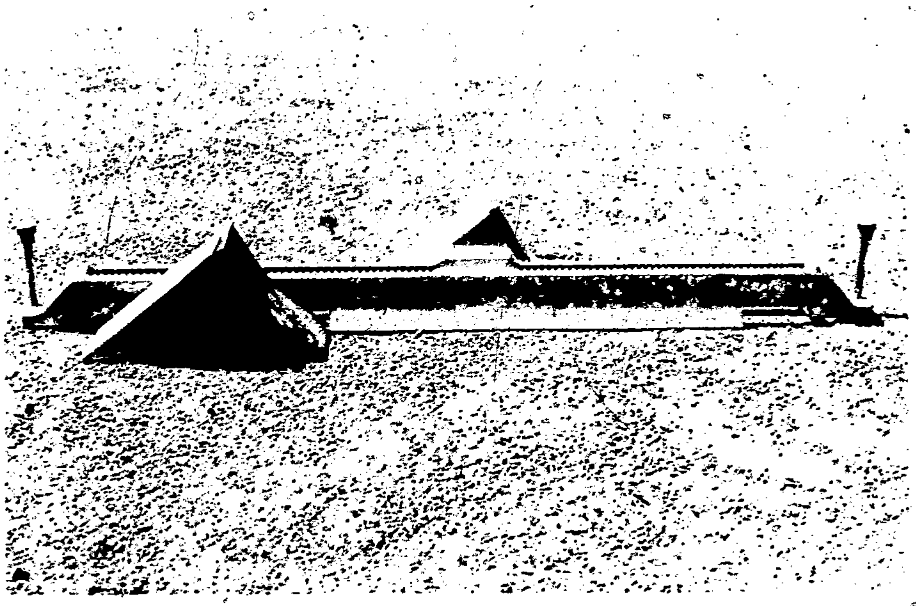
Fig. 7

Can you see why heavy men have an advantage as football players? It may be more difficult for a heavy player to set himself in motion, but once he starts moving it requires more force to stop him or to otherwise change his motion.

<u>Action-Reaction</u>. Newton's Third Law of Motion states essentially that for every <u>contact force</u> there exists an equal and opposite reaction force. This concept of action-reaction can help to explain many activities in contact sports.

Whenever you exert a contact force on an object, that object exerts a similar force upon you. When you kick a football with a certain force, that football pushes your foot right back with a force of the same size. When a bat strikes a baseball, the ball exerts an equal but opposite force upon the bat. When a basketball hits the backboard, the backboard pushed the ball back with the same force with which it was struck.

Two objects are always involved in any action-reaction event. One body can never exert a contact force upon another one without the second one reacting against the first. The reacting force is always equal in size (magnitude) but in an opposite direction from the action force, and no single (solitary) object can act-react upon itself.



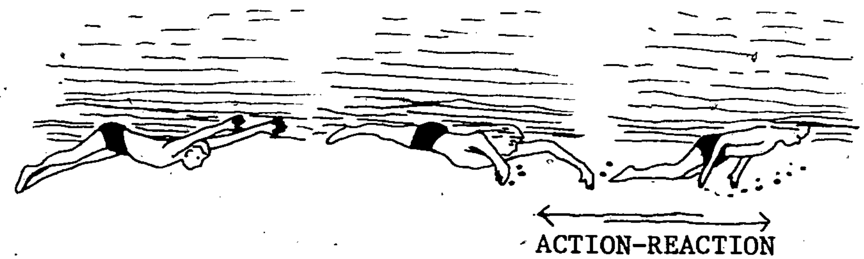
STARTING BLOCKS
Fig. 8(a)

ATHLETE IN HER STARTING POSITION
Fig. 8(b)

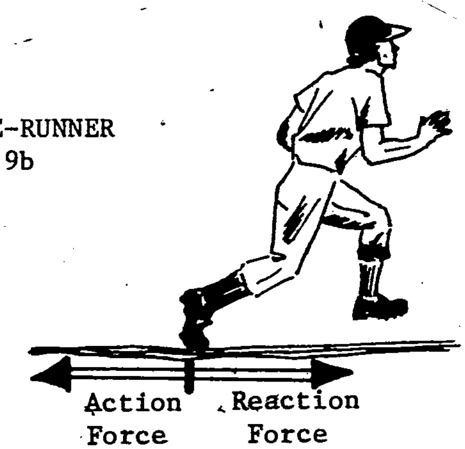
Let's consider some action-reaction aspects of walking and running. You can accelerate forward because you can push backward against the ground. Spiked shoes, cleats, and rubber sneakers are worn by athletes in order to increase friction and to provide better surfaces for action-reaction. A sprinter at the starting line digs her feet into holes (starting blocks). See Figs. 8a and 8b.* Blocks enable the athlete to exert more backward force against the ground when the starting gun is fired, so that the ground can react and push her forward quickly.

A swimmer propels herself because of action-reaction. The resistance force of the water enables the swimmer's hands and feet to exert action forces. The reactions to these forces result in the motion of the swimmer. Figures 9a and 9b below illustrate action-reaction for a swimmer and for a cleated base-runner.

THE BUTTERFLY
Fig. 9a



THE BASE-RUNNER
Fig. 9b



*Courtesy of Dr. Carla Lowry, Physical Education Department, University of Texas at Arlington.

Gravity Force. Newton's Law of Universal Gravitation states essentially that all objects in the universe attract one another. It is this gravity force which pulls everything to the center of mass of our earth. Our common name for the measure of this force is weight.

When a ball is tossed straight up into the air it moves against the gravity force, loses speed, finally stops, reverses direction, and falls back down. The gravity force never stops pulling on the ball; In falling, the ball gathers speed up to the very instant it strikes the earth. It takes just as long for the ball to come down as it took for the ball to peak on the way up. Also, the ball strikes the catcher's glove with the same speed that it left the hand.

Every person must work against (or with) the gravity force when moving from place to place and when performing other like kinds of daily activities. High jumpers, pole vaulters, shot-putters, and discus throwers, for example, are very much aware of this gravity force; but they are not necessarily aware that they are performing mechanical work whenever they move themselves or their equipment upward (against) the gravity force. (Work = Lifting force x Height lifted.)

Let's now consider some technical physics of objects in free fall, such as balls or divers or trampolinists. All objects free of forces other than the gravity force either go straight up and come straight down, or follow a parabolic (specially-curved) trajectory. For example, when a ball is thrown or batted at any angle other than straight up or straight down it always follows a parabolic path. (See Fig. 9). This

is because the earth's gravity force attracts the ball downward with a constant, continuous, even pull from the instant it goes into the air until it returns to the ground. Further, if air friction is disregarded all objects falling from rest (i.e., no initial speed), regardless of weight or size, fall a distance of 16 feet in one second, 64 feet in two seconds, 144 feet in three seconds, etc.

In regard to acceleration (rate at which velocity changes), it makes no difference whether objects are dropped or thrown. Their speeds increase uniformly as time passes. This is called the gravitational acceleration and its value for earth surface regions is approximately a speed increase (decrease) of 32 ft/sec for every second in free fall. This is often written 32 ft/sec^2, or 32 ft/sec/sec.

The curved path taken by balls, bullets, divers, or other projectiles is called trajectory. Players learn from experience what trajectory a ball can be expected to take. An outfielder must estimate a trajectory in order to get under a fly ball. Batters must learn to estimate the trajectories of pitched balls. A catcher must learn to use a low-trajectory throw against an opponent who attempts to steal from first to second base; the low trajectory reduces flight time and the second baseman then has a better chance of tagging the runner.

Football passes, basketball shots, baseball batting, and even the running long jump event are examples of trajectories in sports. Figure 10 on the following page illustrates these.

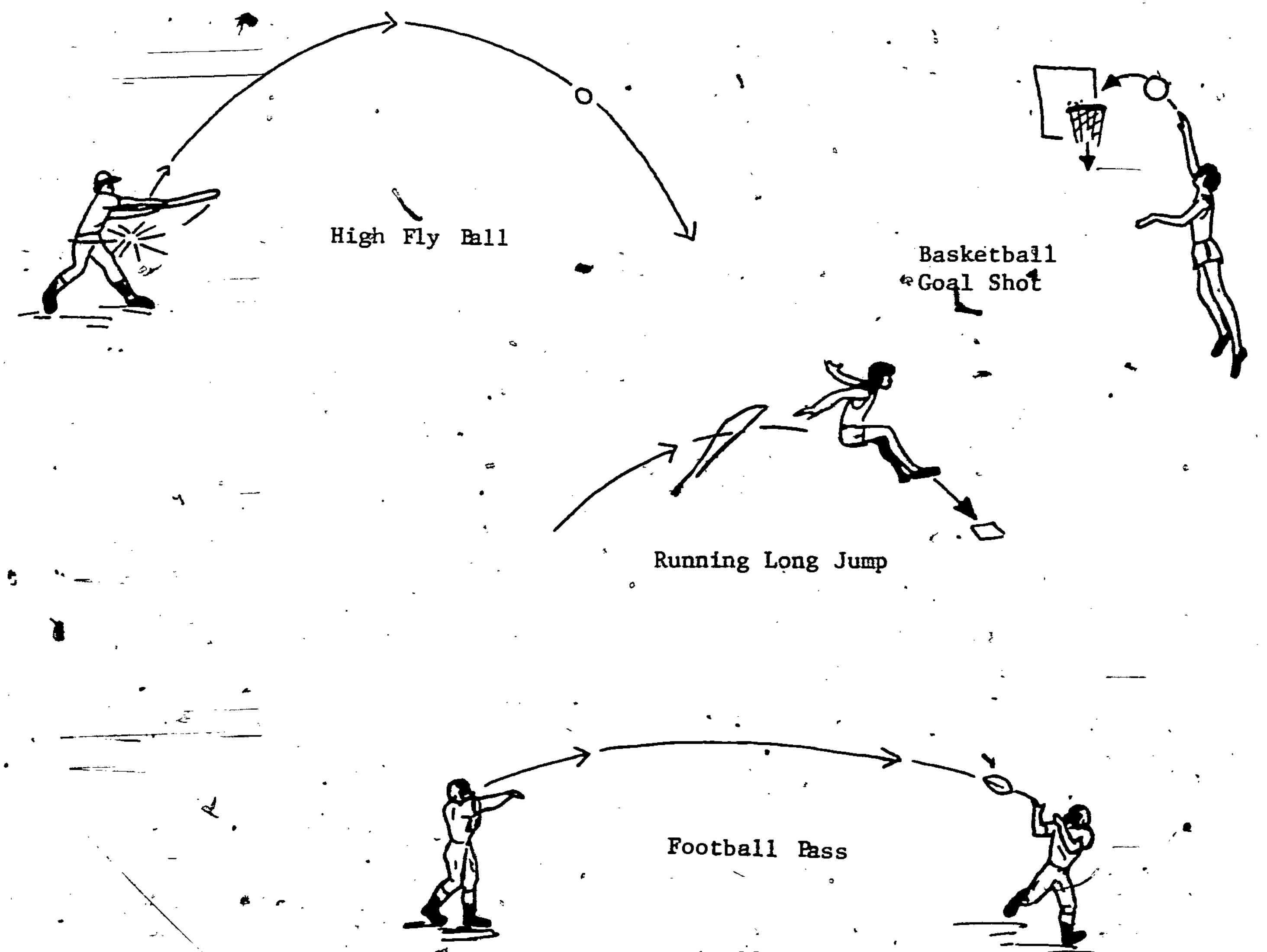
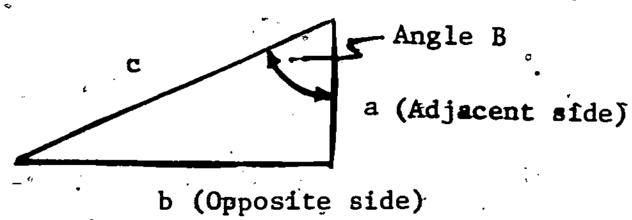


Fig.10
SOME TRAJECTORIES

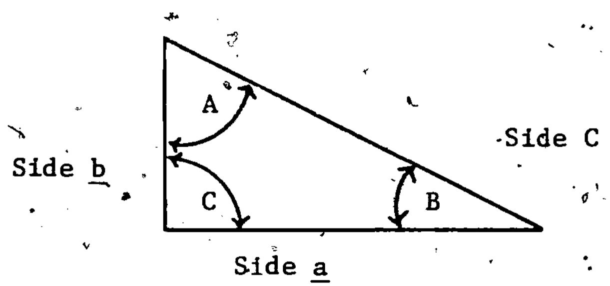
At this point, you may wish to see how the calculaton of trajectories is made. First, here is some simple instruction on common trigonometric functions. Trigonometric functions serve as powerful tools in analyzing and in predicting nature. You need study only the sine (sin), cosine (cos), and tangent (tan) functions for this course. They are simple to understand and simple to use.

Think of a right triangle. It has three straight sides (often lettered a, b, and c), and one of the inside angles (interior angles) is a right angle (90° angle, or "perpendicular" angle, or "square" angle). Examine Figure 10 below. The side c is the hypotenuse; hypotenuse is ALWAYS the name for the longest side. Side a is called the opposite side for angle A only; opposite side is defined as the side opposite whatever angle is being considered. (See Fig. 11 below.)



RIGHT TRIANGLE
Fig. 11

Adjacent side is the side that is left over after you identify the longest side (hypotenuse) and the opposite side; "adjacent side" means the short side "next to" the angle under consideration. In Figure 11 side b is the side adjacent to angle A. Angle letters are often capitalized, to set them apart from side letters (See Figs. 12 and 13). Notice, too, that the smaller angles are always opposite the smaller sides.



RIGHT TRIANGLE
Fig. 12

Learn the following definitions of these three common trigonometric functions. Realize that these definitions represent ratios (fractions) of the lengths of the sides of a given triangle. For example, the tangent of an angle is the name of the fraction made by the length of the side opposite the designated angle divided by the length of the side adjacent to the designated angle. Study Figure 13 carefully.

By Definition	For this Triangle
$\sin = \frac{\text{side opposite length}}{\text{hypotenuse length}}$	$\sin A = \frac{a}{c}$
$\cos = \frac{\text{side adjacent length}}{\text{hypotenuse length}}$	$\cos A = \frac{b}{c}$
$\tan = \frac{\text{side opposite length}}{\text{side adjacent length}}$	$\tan A = \frac{a}{b}$

Right Triangle

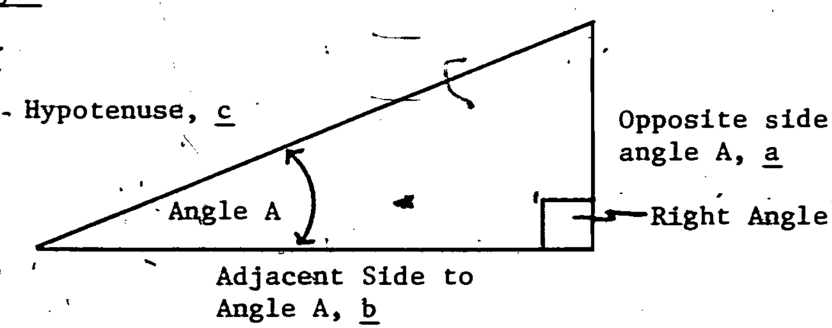
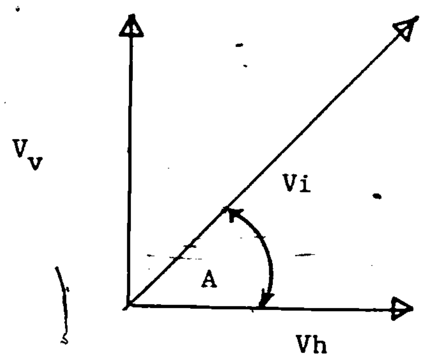


Fig. 13
SOME TRIG FUNCTIONS

Your teacher will show you how to use these trigonometric functions in solving simple problems. Then you can try solving some trajectory problems, if this is your "thing" or if your teacher requires it.

This next section is "heavy". Consider it an optional section for those whose "trip" includes mathematics and for those who plan on taking related courses in college. This section describes how to find the range, height, ~~and time~~ of flight of a ball or other such projectile.

To calculate the height and range of a ball, the initial velocity of the projection is <u>resolved</u> (broken) into a vertical <u>component</u> (part) and into a horizontal component. This is illustrated in Figure 14 below.

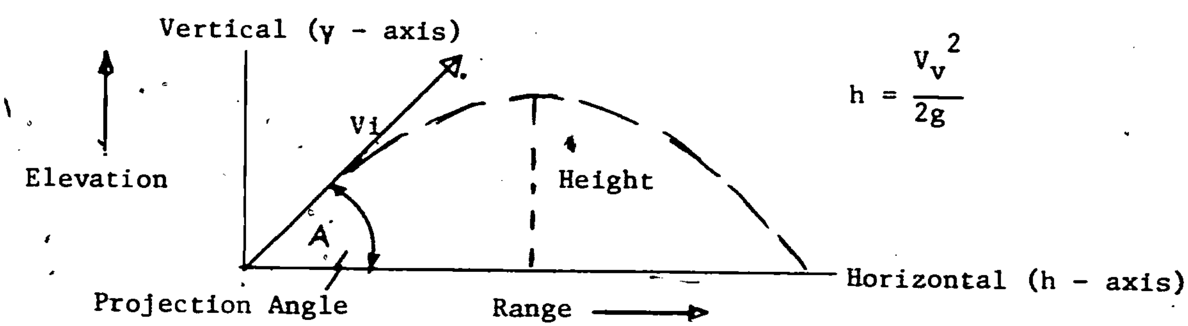


The initial velocity, V_i, can be replaced graphically by the two velocity components Vv (vertical) and V_h (horizontal)

$R = V_h T$

$T = \frac{2(Vv)}{(g)}$

$h = \frac{V_v^2}{2g}$



The path of a ball showing equations for the maximum height, the time of flight, and the range.

BALL TRAJECTORY
Fig. 14

We designate V_i as the velocity of projection of the batted ball, A as the projection (elevation) angle, and V_v and V_h as the vertical and horizontal components of the projection velocity (ball velocity at instant of bat release). These quantities are then related by the trigonometric functions:

$$\text{Sin A} = \frac{V_v}{V_i} \quad \text{and} \quad \text{Cos A} = \frac{V_h}{V_i}$$

Multiplying both sides of each equation by V_i yields

$$V_v = V_i \text{ Sin A}$$

$$V_h = V_i \text{ Cos A}$$

The ball trajectory can be thought of as two independent motions: (1) the motion of a ball batted vertically upward with an initial velocity $\underline{V_v}$ (which will change constantly in flight) and (2) the motion of a ball batted horizontally with an initial velocity V_h (which will remain constant during flight). In other words, any ball batted vertically upward with a velocity V_v will rise to the same height, and do so in exactly the same time, as our original ball projected at an angle A and with a velocity V_i. Further, any ball batted horizontally with a velocity V_h will move the same distance (range) in exactly the same time as our original ball projected at an angle A and with a velocity V_i.

Since the time required for the ball to reach its highest point is equal to the time required for it to fall the same distance back to the ground, the formula for free fall from rest is used to find the time of fall. We deal only with the changing velocity component V_v:

$$V_v = gt$$

Solving for t, by dividing both sides by g, we get

$$t = \frac{V_v}{g}$$

Substituting $V_v = V_i \text{ Sin } A$ yields

$$t = \frac{V_i \text{ Sin } A}{g}$$

Because this t is the time for the ball to fall, the total time of flight will be 2t. Therefore, if we designate 2t as T, (the total flight time) we get

$$T = 2t$$

$$= \frac{2V_v}{g}$$

$$= \frac{2V_i \text{ Sin } A}{g}$$ (Our equation for the time the ball will be airborne).

To find the height h, the general equation for free fall from rest $V_i^2 = 2gd$* is used. The letter d (for distance) is replaced by h (for height) and the letter V_i is replaced by V_v (for vertical). Then,

$$(V_v)^2 = 2gh$$

* For more about this equation and its derivation, see any general physics text.

Solve for h (by dividing both sides of the equation by 2g) and get

$$\frac{(V_v)^2}{2g} = \frac{2gh}{2g}$$

2g divides out of the right side of the equation, and

$$\frac{(V_v)^2}{2g} = h$$

Thus, maximum height $h = \frac{(V_v)^2}{2g}$

Substituting V_i Sin A = V_v, we get

$$h = \frac{(V_i \text{ Sin } A)^2}{2g}$$ (The maximum height of the batted ball).

To find the range R, use the general equation,

distance = rate x time

$$d = rt$$

Use R (range) for distance, use V_h (horizontal speed) for rate, and use T (total time of flight) for time. This yields

$$d = rt$$

$$R = V_h T$$

Substituting V_i Cos A = V_h,

$$R = V_i\ (\text{Cos A})\ (T)$$

Substituting $\frac{2\ V_1\ \text{Sin A}}{g}$ for T.

$$R = \frac{(V_i\ \text{Cos A})(2V_i \text{Sin A})}{g}$$

Multiplying the right side factors

$$R = \frac{2V_i V_i\ \text{Cos A SinA}}{g}$$

$$= \frac{2V_i^2\ \text{Cos A Sin A}}{g}$$ (The range of the ball).

If this range equation looks "messy," ask your teacher about double-angle trig formulas. It can be re-written more simply by using double-angle formulas, but this form demands no knowledge of trig functions other than sine and cosine.

RESOURCE PACKAGE 1-8

INVESTIGATING SOME PHYSICS OF SPORTS

First, you will examine some physics of baseball.

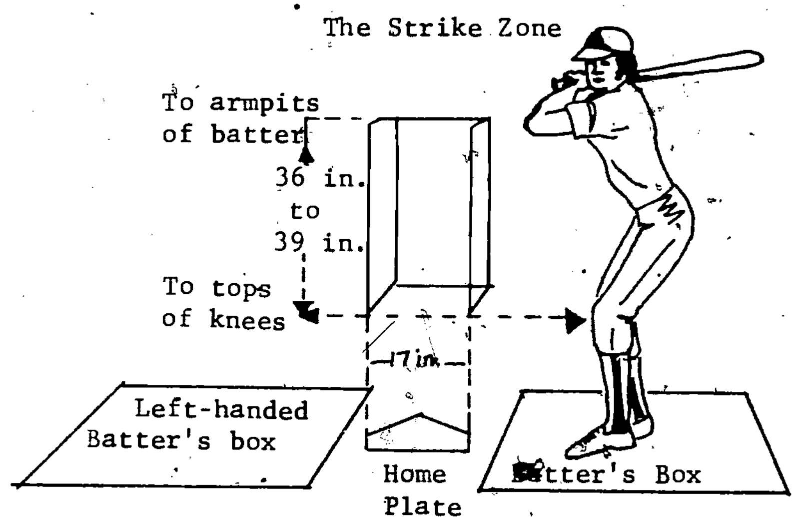
<u>Investigation I</u>: Pitching a Baseball

Purpose: To investigate some physics of pitching, especially:

a) Why a pitcher's mound is needed.
b) How to pitch some basic types of balls and why these pitched balls behave as they do.

Materials: Baseball, bat, glove, catcher's mit, and catcher's protective gear,

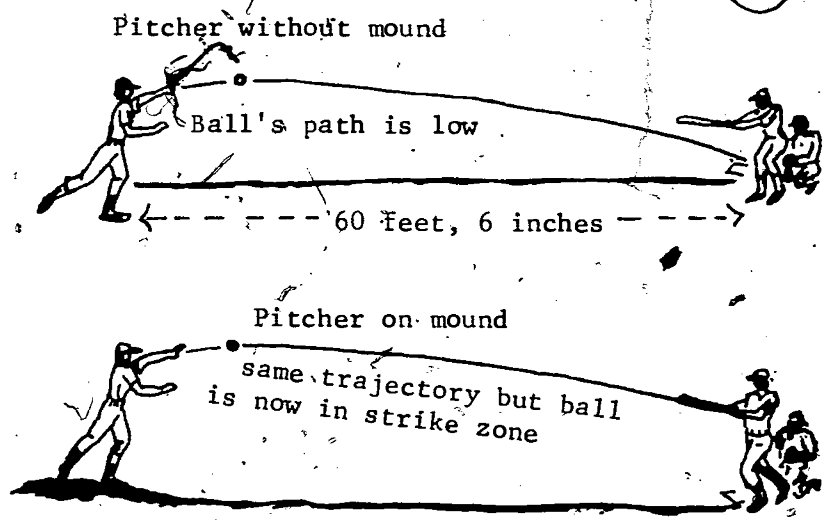
Procedure: You will need classmates to work with you on this activity. First, study carefully the strike zone shown in Fig. 11.



THE STRIKE ZONE
Fig. 11

Get someone to stand in the batter's box while you try to pitch without a mound. Next, use the mound and try to pitch from it to the batter's box. Do you notice any difference? You should be able now to answer the big question. Why does pitcher need a mound? Hint: The pitcher stands on a little hill or mound. The nearest edge of the pitcher's plate is 60 ft, 6 in from home base. The ball is hurled toward the strike zone. The instant the ball leaves the pitcher's hand, it is in "free fall" and it begins to drop!

Any pitched ball drops considerably over a $60\frac{1}{2}$-ft distance. The pitcher's mound is raised about 10 inches above the level of the home plate to compensate for this dropping. But even with this aid, a pitcher still has to throw every ball slightly upward. See Fig. 12.



EFFECT OF PITCHER'S MOUND
Fig. 12

The basic types of pitched balls are described next. You will learn how to grip the baseball so that you can throw these pitches:

1) The fast ball -- See Fig. 13.

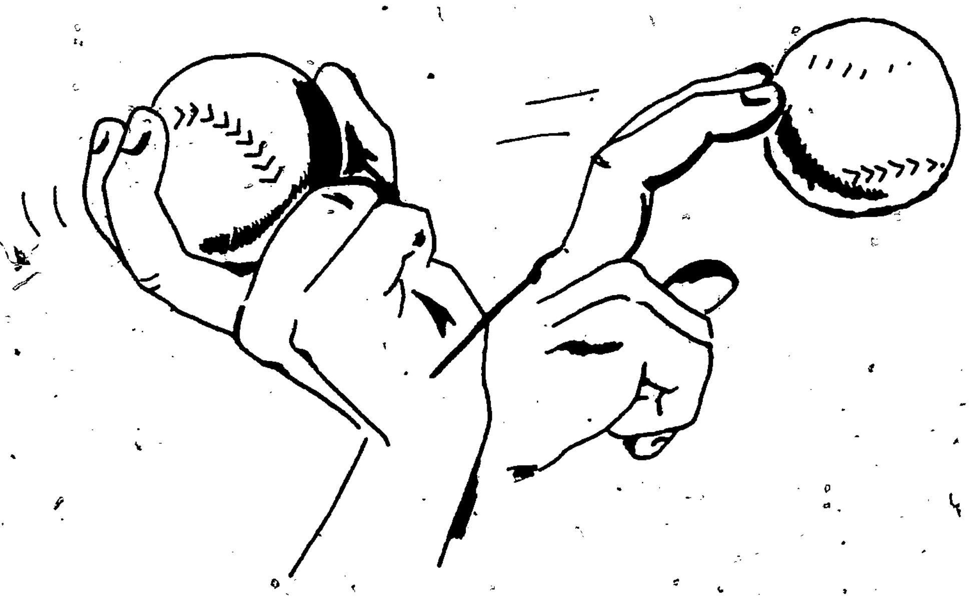
2) The curve ball -- See Fig. 14.

3) The screw ball -- See Fig. 15.

4) The knuckle ball -- See Fig. 16.

5) The ~~slow~~ ball -- See Fig. 17.

It is probably easiest to learn most of these pitches using a light ball, such as a tennis ball.



THE FAST BALL
Fig. 13

You will follow the drawing and try to throw a fast ball. You develop a good fast ball delivery by keeping your wrist supple (loose) and using your arm like a buggy whip. Naturally, you must be able to coordinate your whole body throughout the delivery. The ball should roll from the ends of the fingers as the wrist snaps down at the instant of delivery.

Professional pitchers must have speed and control (be able to curve the ball, to change pace of the ball, etc.). How fast is a fast ball? Professionals can throw a fast ball about 100 miles per hour. You may injure your arm by throwing too hard. Be careful. But see if you can learn to throw all five types of balls listed in this section.

Next, try to throw the curve ball. See Fig. 14 for an illustration of how to grip, twist, and throw a curve ball.

The curve ball can be delivered by using outward (away from your body) rotation of the arm and wrist. The wrist is snapped as the ball is released.

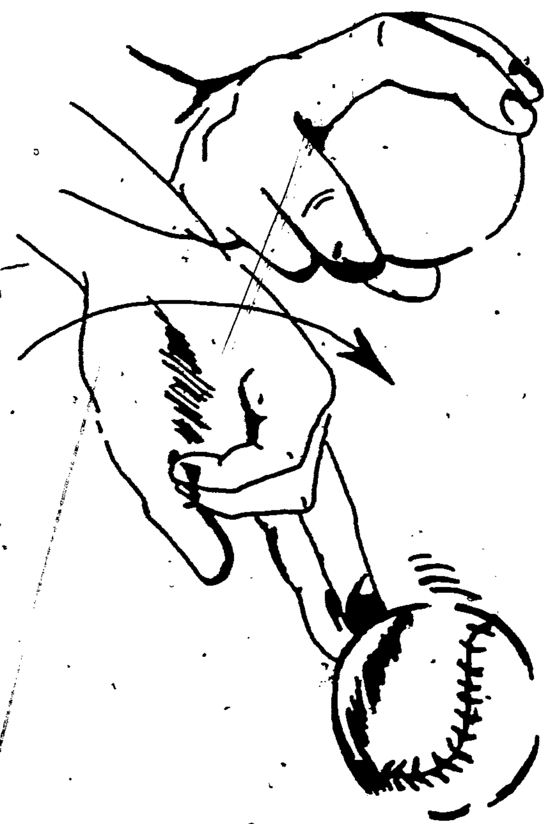
Bring the arm forward just as you would to pitch a fast ball. When the arm is opposite your ear, start the arm rotation. Build up speed (linear momentum) before the release of the ball. For best results, work from a slow curve to a fast curve. The "break" (sharp curve of the ball in flight) is ~~more~~ important than the speed of the ball. Spin the ball with your middle finger, and let the ball roll out over your index finger.

THE CURVE BALL
Fig. 14

Now try hurling the screw ball (See Fig. 15). You spin a screw ball away from the fingers with an inward (toward the body) rotation of the arm and wrist.

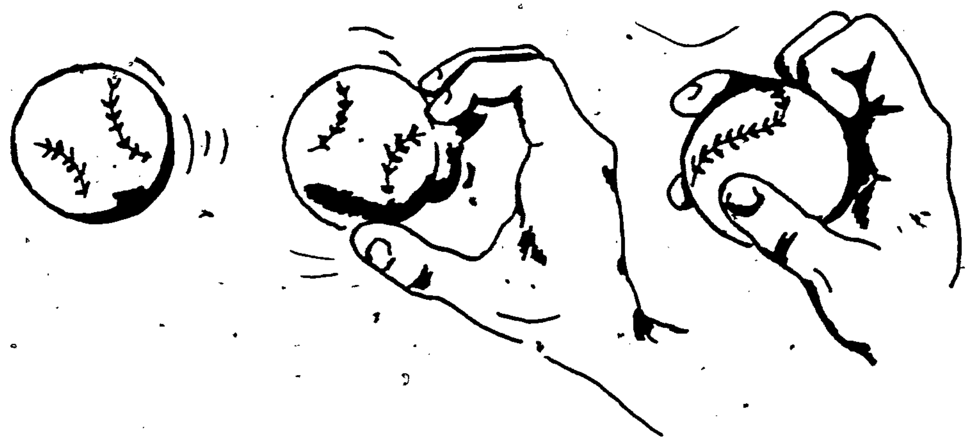
The screw ball is sometimes called a reverse curve, because the direction of the break is opposite that of the usual curve.

You may have real difficulty trying to throw the screw ball, but it will be fun to try!



THE SCREW BALL
Fig. 15

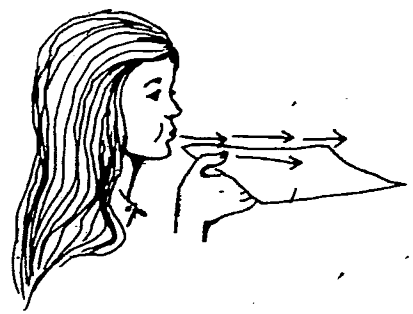
Study the illustrations of Figure 16 carefully. Then, try to throw the knuckle ball.



THE KNUCKLE BALL
Fig. 16

Notice how the ball is released; this pitch differs from the "finger tip" type of ball delivery. In this type of knuckle ball, the first two fingers are extended to pitch the ball. Notice the wrist action. The extension of the finger spins the ball downward, causing it to drop sharply. This makes the pitch very difficult to control.

Try following activities related to curving baseballs. First hold the top edge of a piece of notebook paper as shown. Blow at constant speed across the top edge of the paper. Record what happens.

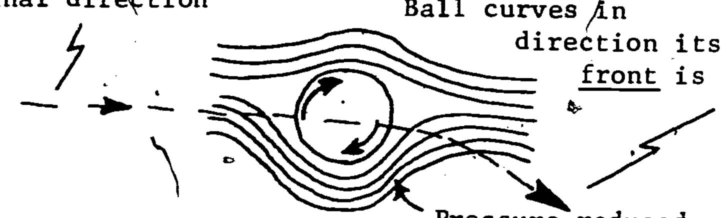


Repeat the activity, but this time blow a little harder yet at a constant rate. Explain this activity in terms of Bernoulli's Principle and relate this observed notebook paper action to a curved baseball.

Next, hold a spool and card (with "centering" pin) as shown. As you blow evenly through the spool hole, drop your head from an upward to a downward position. Account for the card's defiance of gravity!

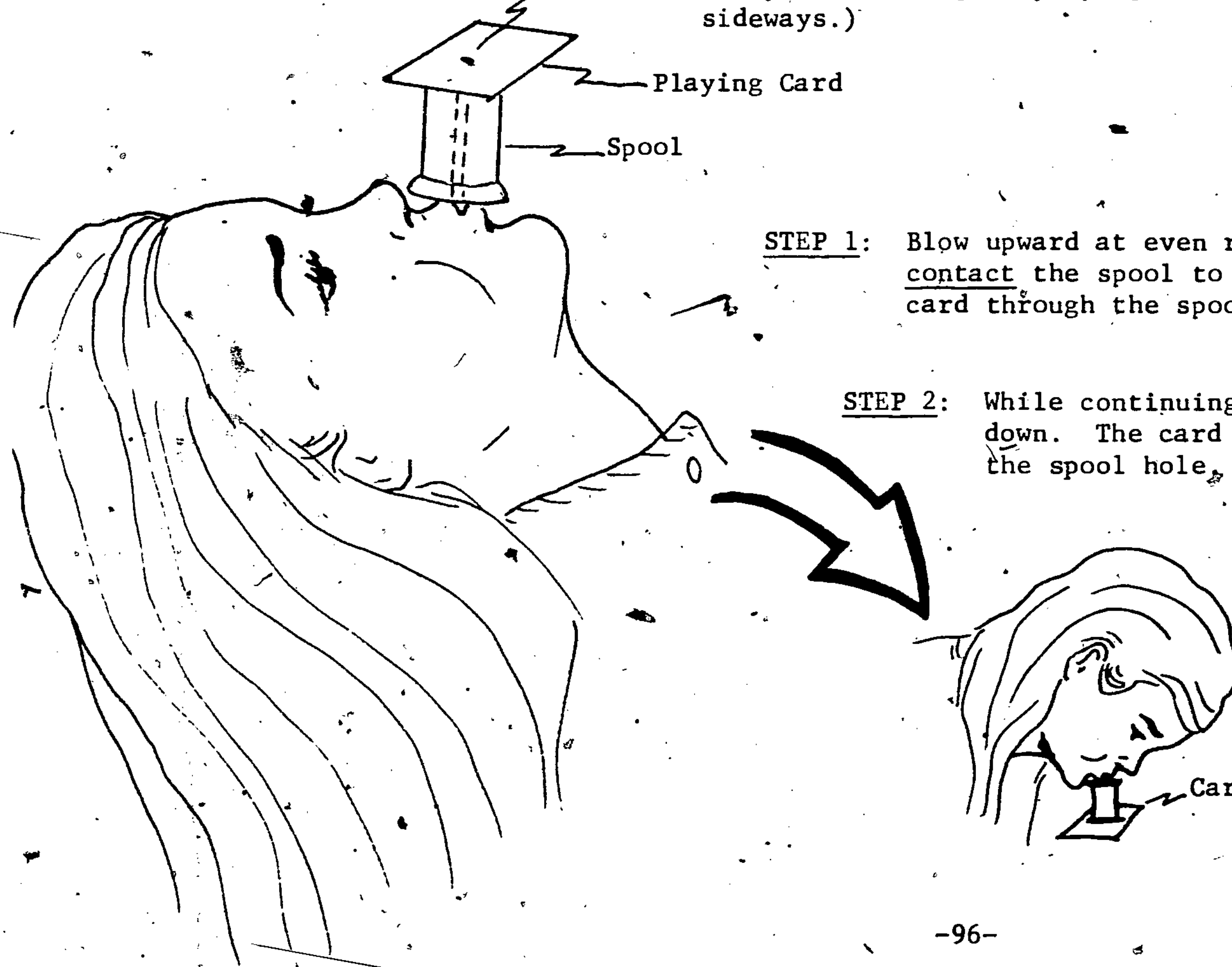
The slow ball is also a basic kind of pitched ball. Use the same finger tip control as for the fast ball. However, the ball should be delivered at about half speed. Keep your wind up and your delivery the same as for the fast ball, but "drag" your back foot instead of swinging it around forward quickly. This slows down arm action, and a slower delivery results. The slow ball is used when a pitcher wishes to change pace in order to fool the batter. Practice pitching a slow ball.

You are now ready to consider the question, why does a ball curve? A pitcher makes the ball curve by giving the wrist a snap as he releases the ball. The ball comes off the side of the index finger and his thumb. Aided by the friction of the pitcher's fingers against the seams, the ball is set spinning about some axis. Look at Fig. 17; study it closely. (This is a bird's-eye view of the ball; you are looking down on it!)



Top view of the air stream near a curving baseball. The air pressure is reduced most where the speed of the air stream is greatest.

A CURVED BALL
Fig. 17



STEP 1: Blow upward at even rate through spool hole (Lips must contact the spool to insure that air travels to the card through the spool only, not around it.)

STEP 2: While continuing to blow, turn your head upside down. The card will not fall, if you blow through the spool hole.

Now that you have finished Investigation I, turn in the data and answers to questions to your teacher for evaluation.

Investigation II: Batting A Baseball

Purpose: To investigate some of the physics of batting, especially in terms of:

a) the importance of hitting a ball at a certain spot on a bat

b) how to hit pitched balls that are too high, too low, or nearly out of the strike zone

c) what happens physics-wise when you hit a ball.

Materials: Baseball, bat, glove, catcher's mit, and catcher's protective gear.

Procedure: You will go outdoors for batting practice. But before you go, study some important facts about bats and batting in the sections which follow.

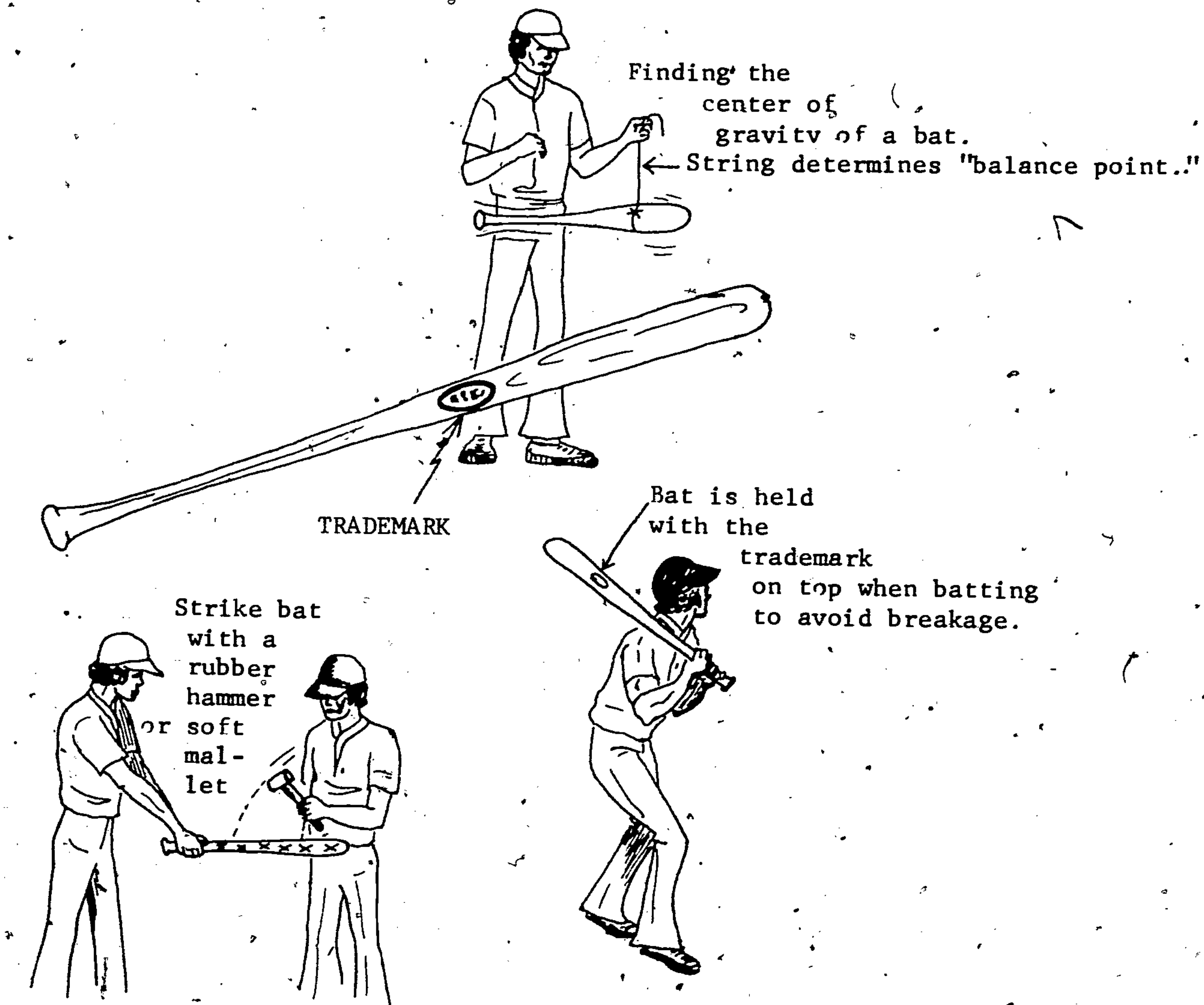
Center of Percussion, The "Sweet Spot," or Why Bats Sometimes Sting. You will find that there is one best spot on a bat for hitting a ball the greatest distance. When the ball is hit on this spot, there is a clear solid sound and the bat does not sting the hands.

You can find this spot on any bat. (See Fig. 18) Hold the bat horizontally in one hand. Now pick up a rubber hammer or piece of soft wood, and strike the bat at points about one inch a part. Start from the heavier end of the bat. Do not put dents in the bat.

You will find one small area (spot) which gives the most solid ring; and at this spot the hand holding the bat will not feel vibration or sting. Mark this spot. You have found the bat's <u>center of percussion</u>, or <u>sweet spot</u>. It is a "spot" where the momentum (energy) of the batter's swing is best transferred to the ball. This spot is usually between 2 inches to 10 inches from the thick end of the bat.

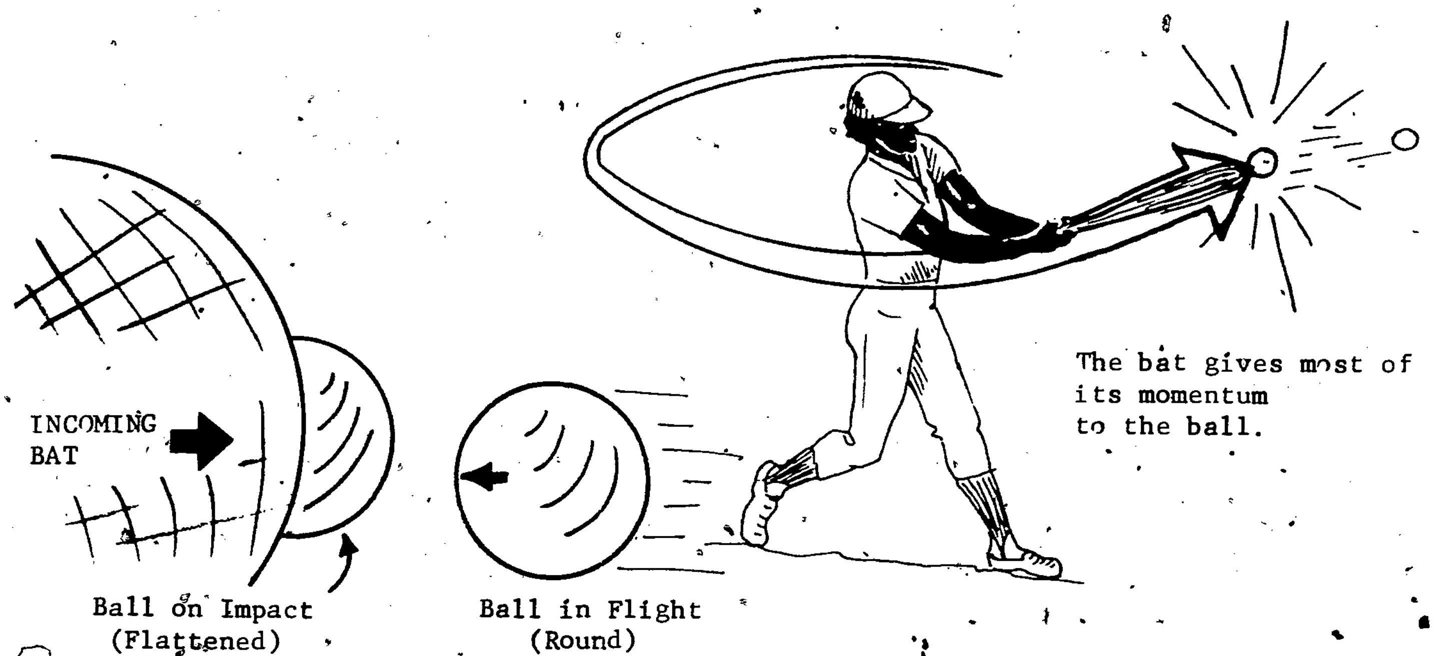
If the ball is struck anywhere other than at the percussion center the bat <u>tries</u> to <u>swing</u>, <u>rotate</u>, or <u>twist</u> around this <u>percussion point</u>. This twisting force will act to wrench the bat out of your hands. Physics-wise this wrenching results in a series of back-and-forth movements, called <u>vibrations</u> or <u>oscillations</u>, which make the bat "sting." Because a certain portion of the total "swing energy" of the batter is "wasted" in making the bat oscillate, and because energy transfer from bat to ball is most efficient at the "sweet spot," the ball travels farthest when it is hit at the bat's percussive center.

For a freely-suspended bat, the "sweet spot" is essentially the <u>center of gravity</u> of the bat (the space point where all the weight or inertial mass property of the bat seems to be concentrated). However, the center of percussion shifts slightly from that of the <u>bat alone</u> when the bat is gripped (suspended) by the batter's hands. This is because the <u>bat-plus-hands</u> constitutes a combined system with a new center of percussion! You can find the center of gravity of a bat by using a string as shown in Fig. 18.



FINDING THE CENTER OF PERCUSSION AND THE CENTER OF GRAVITY OF A BAT
Fig. 18

<u>Conservation of momentum</u>. Physics tells us that in a perfect collision of two elastic objects, one body gains whatever momentum the other body loses. When you hit a baseball with a bat, the bat exerts an impulse on the ball, slows down, and transfers momentum (energy) to the ball. Because a bat-ball system interaction is not "perfect," frictional energy losses occur and the momentum (energy) the ball gains is somewhat less than the momentum (energy) the bat loses. See Fig. 19.



BATTED BALL AND MOMENTUM CONSERVATION
Fig. 19

You will practice batting. Using the knowledge you have gained, try to increase the distance a ball will travel when you hit it. Comment on these trials in your report to your teacher.

Next, perform this little simple experiment. Throw a slow ball against a brick wall or some other rigid wall. Record the distance that the ball rebounds from a given wall height. Now throw a fast ball against the same wall and as close to the same height as possible. Compare distances and see if you have quantitative (numerical) data or evidence that the wall pushes back harder on the faster ball.

You probably have quantitative proof that the wall pushes the faster balls back faster. A bat acts in the same manner as the wall, except that the bat is moving before impact. The reason a fast ball is batted back so much faster than a slow ball is that the harder a ball hits the bat, the more it is squeezed out of shape. As it goes back to its original round condition, it gets an additional push off the bat!

Write up the results of this section. Relate your write-up to momentum conservation, energy conservation, and action-reaction wherever possible.

Placement of Hits. There are many conditions which determine where a ball will go after it is batted. This is really quite a complicated matter. Baseball players spend many years studying and practicing to perfect their placement of hits.

During your batting practice, try the few things discussed in this section to help you direct your hits. In general, placement of hits depends upon:

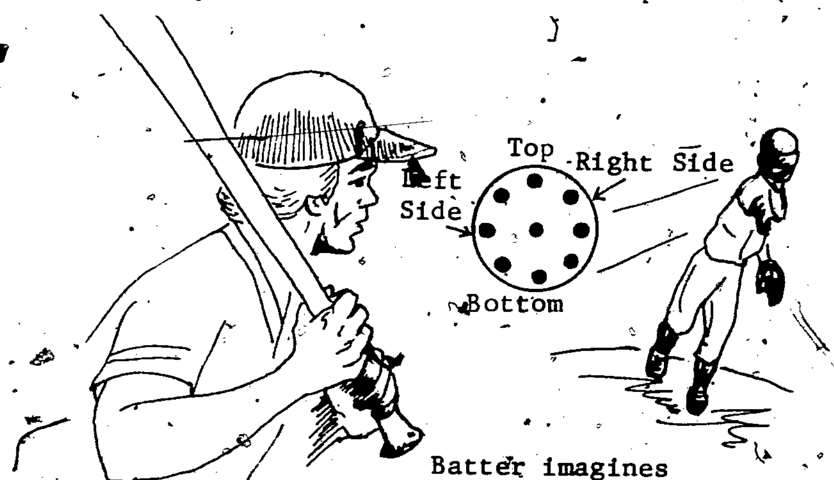
a) the position and direction of the bat at the moment of impact

b) the part of the ball being struck

c) the area of the bat being struck

d) the follow-through and "touch" of the batter

Consider the ball as having nine spots as it comes toward the plate. (See Fig. 20.)



THE NINE-SPOTTED BALL
Fig. 20

If a lower spot is struck, the ball will tend to go <u>upward</u> as it leaves the batter.

If any upper spot is struck, the ball will tend to go <u>downward</u>.

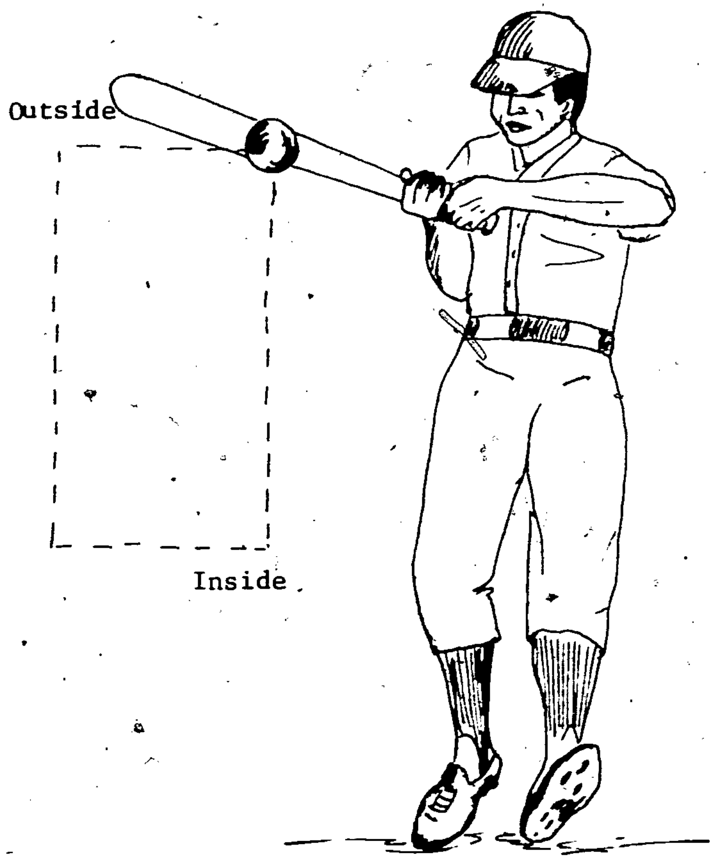
If the center spot is struck, the ball will be batted neither up nor down. It will tend to go straight ahead.

Hitting any right spot will make the ball go to the <u>left</u>.

Hitting any left spot will make the ball go to the <u>right</u>.

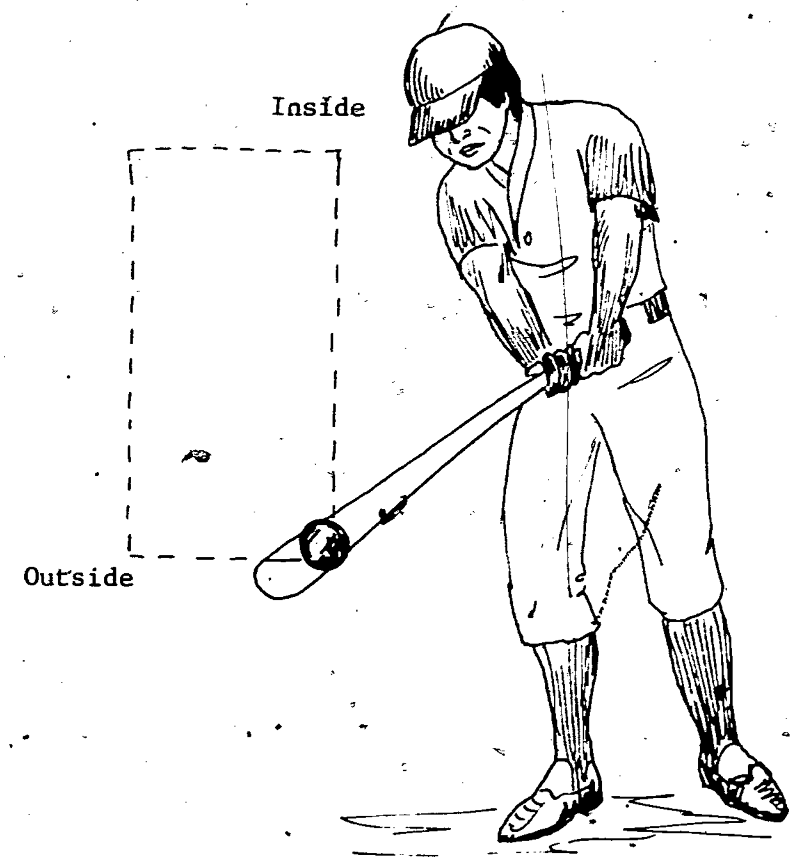
<u>Hitting High and Low Balls</u>. Look at Fig. 21 and Fig. 22 to see how you can best hit a ball thrown high inside or low inside.

How to hit a high inside pitch.



HIGH PITCH INSIDE
Fig. 21

How to hit a low inside pitch.



LOW PITCH INSIDE
Fig. 22

HENRY AARON'S HOME-RUN OUTPUT

If you "groove on sports" you are impressed with the performance of our black athletes. And if you "groove on baseball" you are impressed by the home-run performance of the Atlanta Braves' Henry Aaron, one of the greatest batters in baseball's history.

In technical physics things which actually occur in the real world are represented by numbers, by equations, and by graphs.

In this activity you will learn something about graphs by plotting (making a picture of) the home-run output of the great athlete Aaron between the years 1954 and 1973. You are to plot the total home runs on the vertical axis (y-axis) and the number of years that Aaron was in major league baseball on the horizontal axis (x-axis). Your teacher will help you get started, if you have had no graphing experience. Also, a set of suggested axes is presented in the diagram that follows. (See upper right hand corner, next page.)

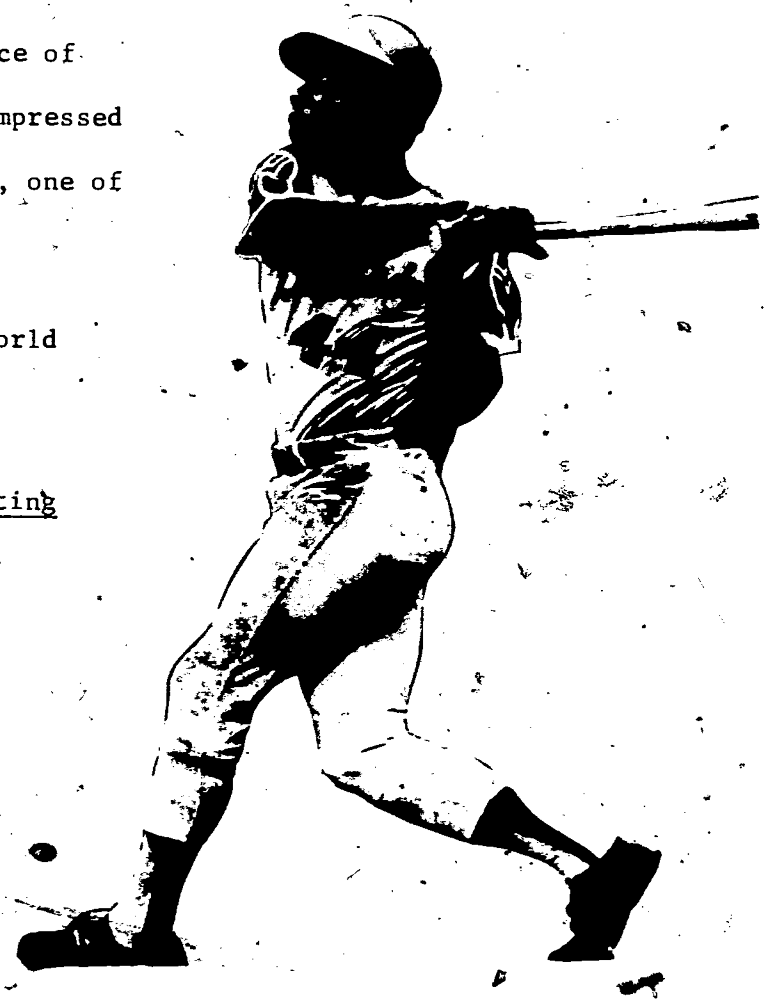
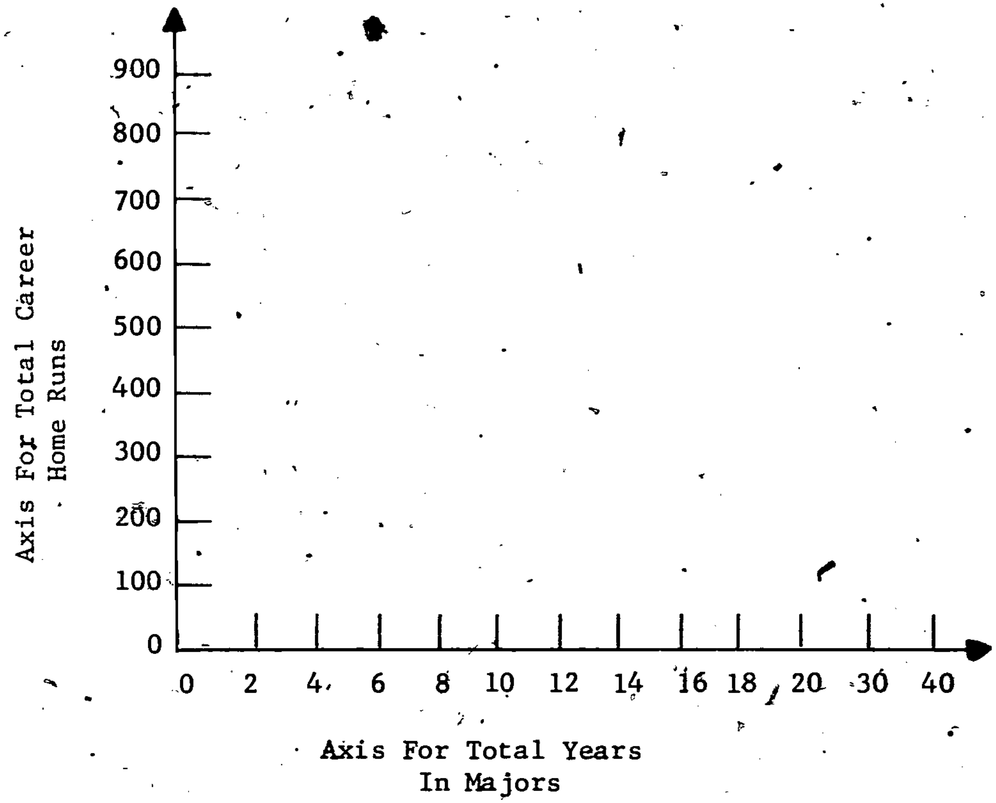


Photo courtesy of the Atlanta Braves.

The data you will plot (place) on the graph area between the "Total Career Home-Runs" axis and the "Total Years in Majors" axis are presented in the table below.

Years in Majors	Calendar Year	Home runs in that year	Total career home runs
1954	1	13	13
1955	2	27	40
1956	3	26	66
1957	4	44	110
1958	5	30	140
1959	6	39	179
1960	7	40	219
1961	8	34	253
1962	9	45	298
1963	10	44	342
1964	11	24	366
1965	12	32	398
1966	13	44	442
1967	14	39	481
1968	15	29	510
1969	16	44	554
1970	17	38	592
1971	18	47	639
1972	19	34	673
1973	20	40	713

HENRY AARON DATA



SUGGESTED AXES

Plotted data can yield straight lines or curved lines. These lines may be at various angles. Graphs of position-vs-time data will yield a parabolic curve graph for a ball in free fall, a circle curve graph for the early portion of the hammer in the hammer throw, a straight line curve for a contestant in a 50-yard dash, etc.

After you have plotted the data points and connected them with a solid line to form a smooth curve, write out answers to the following:

1) Describe the curve (circle, parabola, straight line, spiral, or ?).

2) Associate a slope with this curve.

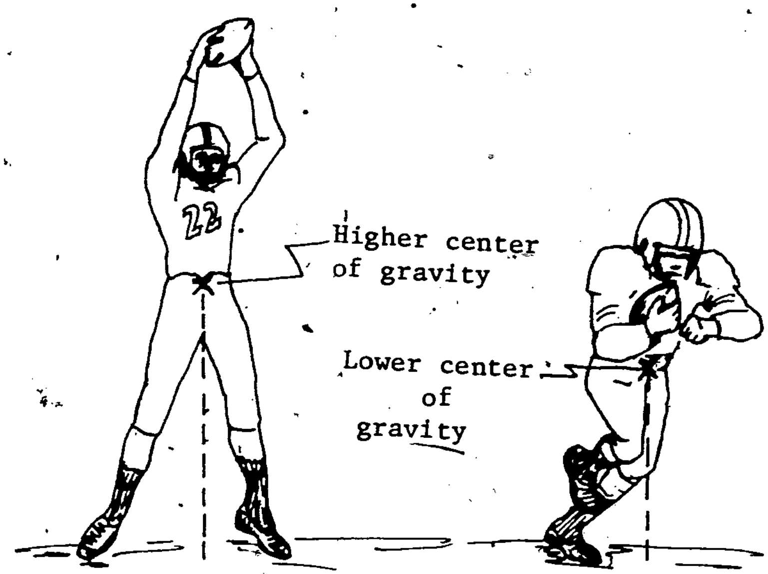
3) Relate this curve to any of the terms: "is directly proportional to," "is inversely proportional to," "is not related to," and "is a function of?"

4) If Aaron's past performance is an accurate prediction of the future, how many home runs would you expect him to hit after 35 years in the majors?

INVESTIGATION III: Stability and Center of Gravity

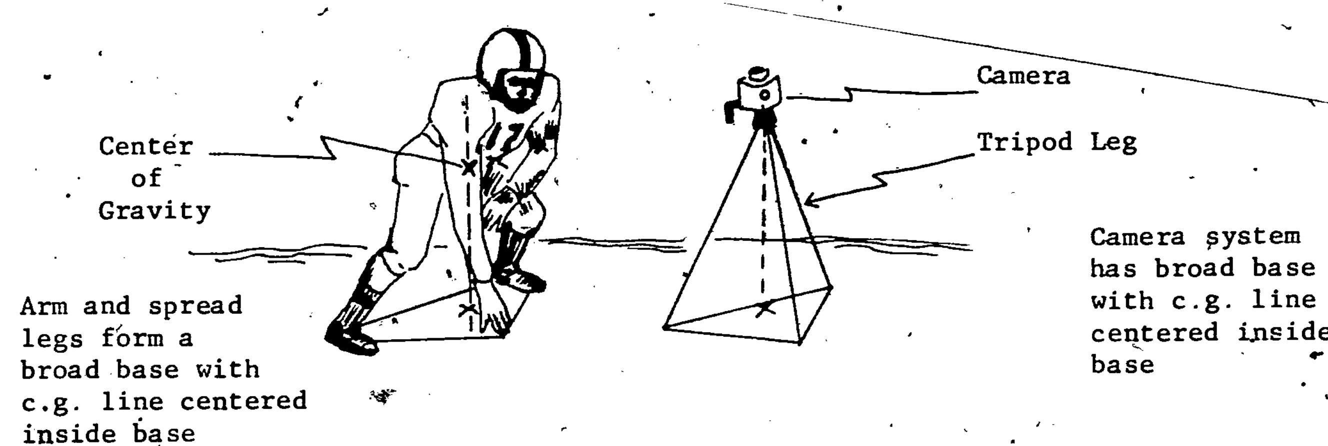
Stability. If you consider the physics of football, you will realize that _stability_ plays a key role. You are going to investigate why stability is so important in football. Football is a game where a player is stopped in his advance by being thrown to the ground. He may have his balance (stability) upset by tackling, blocking, or other means. The better player learns how to make himself more stable, and how to return quickly to his original stable state (position) when pushed or pulled.

Center of gravity plays an important part in stability. It is easy to balance a stick at its center of gravity, the point where all the weight seems to be concentrated. A football player, too, has a center of gravity. When he stands up, his center of gravity rises. When he crouches, his center of gravity lowers. A player gets greater stability by crouching and making his center of gravity lower. See Fig. 23.



CENTER OF GRAVITY
Fig. 23

Stability is also increased whenever the support base is broadened. The broader the base of an object, the harder it is to tip over. (Imagine trying to tip over a pyramid!). To increase his stability a football player should make as broad a base as possible. See Fig. 24.

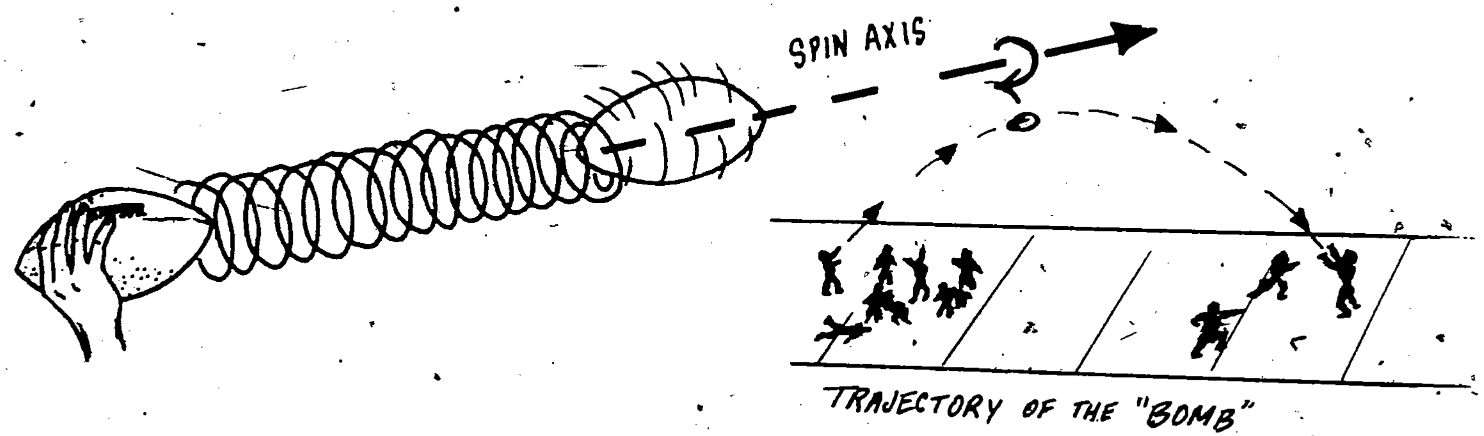


BROAD STABLE BASES
Fig. 24.

It is apparent that the greater the impact (impulse or momentum transfer) a player receives, the easier it should be to knock him over (disturb his stability). You have learned that momentum cannot be destroyed, but that it can be transferred. A football carrier who is tackled, obviously receives some of the momentum of the tackler. If this momentum transfer causes him to move so that his center of gravity is suddenly forced to fall outside his support base, he loses his stability and falls. Arrange your body in various configurations and have a <u>friend</u> push on you. Relate your stability to the physics discussed in this section.

INVESTIGATION IV. Throwing A Football

A good passer spins the football because when it is spinning smoothly it is easier to catch, it travels faster and farther, and it has a more accurate trajectory (stability in flight). The spinning ball has a very special kind of <u>inertia</u> property that is associated with all things that spin. It is called <u>inertial</u> <u>moment</u> and it represents a behavior of all spinning objects; namely, an object which is rotating about an axis will continue to rotate about that axis unless some force (moment) causes a change. Thus, a spinning ball tends to keep its spin axis in a constant direction despite the gravity force (See Fig. 25). This is sometimes called the "gyroscope effect." The passer's fingers and wrist set the ball rotating around the ball's axis (end-to-end axis). See Fig. 25.



SPIN-STABILIZED FOOTBALL
Fig. 25

Because of its inertial moment property, the ball will tend to continue spinning and will resist any change in direction of the spinning axis. Thus, the ball does not tumble end-over-end during flight. Further, because it is most streamlined along its longitudinal (end-to-end) axis, it offers least friction surface and can therefore travel faster and farther.

Write out responses to the following:

a) Why are gun barrels rifled?

b) Discuss the relative positions (orientations) of a spin-stabilized spherical communication satellite in a circular near-earth orbit.

c) Toss a football end over end. Now toss it with spin. Compare distances tossed and report the <u>per cent</u> increase or decrease in maximum distance for your spin-stabilized pass.

<u>INVESTIGATION V</u>: Finding Physics In Action

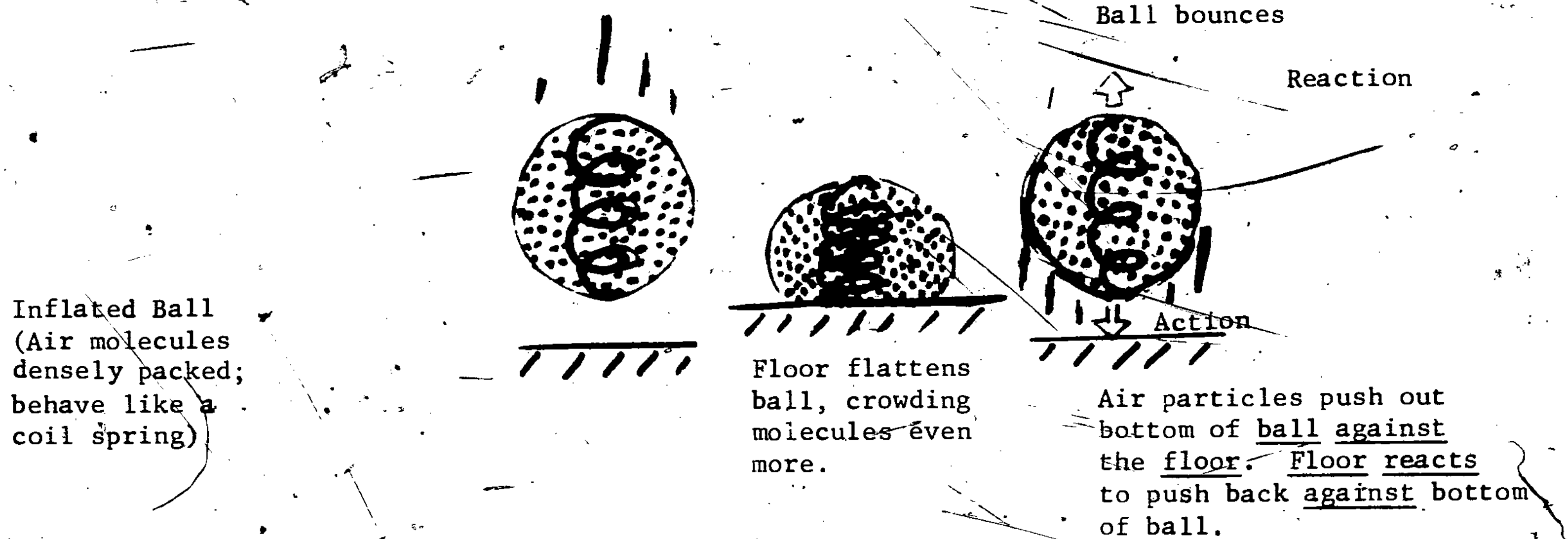
<u>Option I</u>: Go to an official football game. Make a list of the principles of physics you see being demonstrated on the field (A simple sketch should accompany each principle.). Look for such things as examples of Newton's Three Laws of Motion, conservation of linear and angular momenta, impulse, velocity, friction, etc. Turn your notes and sketches in to your teacher for evaluation.

<u>Option II</u>: Borrow film from a football coach and view it while looking for the same things set forth in Option I. Turn this list in to your teacher for evaluation.

Option III: Design some demonstrations of the principles of Options I and II that can be carried out on the football field. Write up the demonstration procedures and observations and turn them in to your teacher for evaluation.

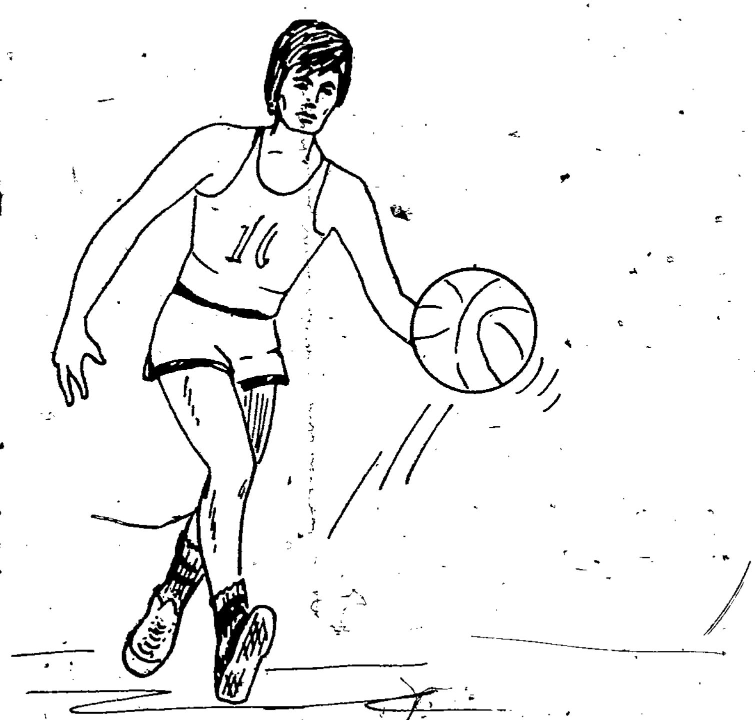
INVESTIGATION VI: Dribbling A Basketball.

Basketball is a game of speed. It is one of the fastest foot games. When a basketball strikes the solid floor it does NOT rebound instantly, but continues to move floorward because of its inertia property. This causes the ball to flatten against the floor. The close-packed particles of air inside are squeezed even closer together (An inflated ball has its air molecules packed densely, even before it is squeezed by bouncing.). Bouncing further compresses the air and this air acts as a compressed spring. This compression forces the flattened part of the ball to push hard against the floor; the reaction of the floor pushes the ball away from the floor. See Fig. 26 and Fig. 27.

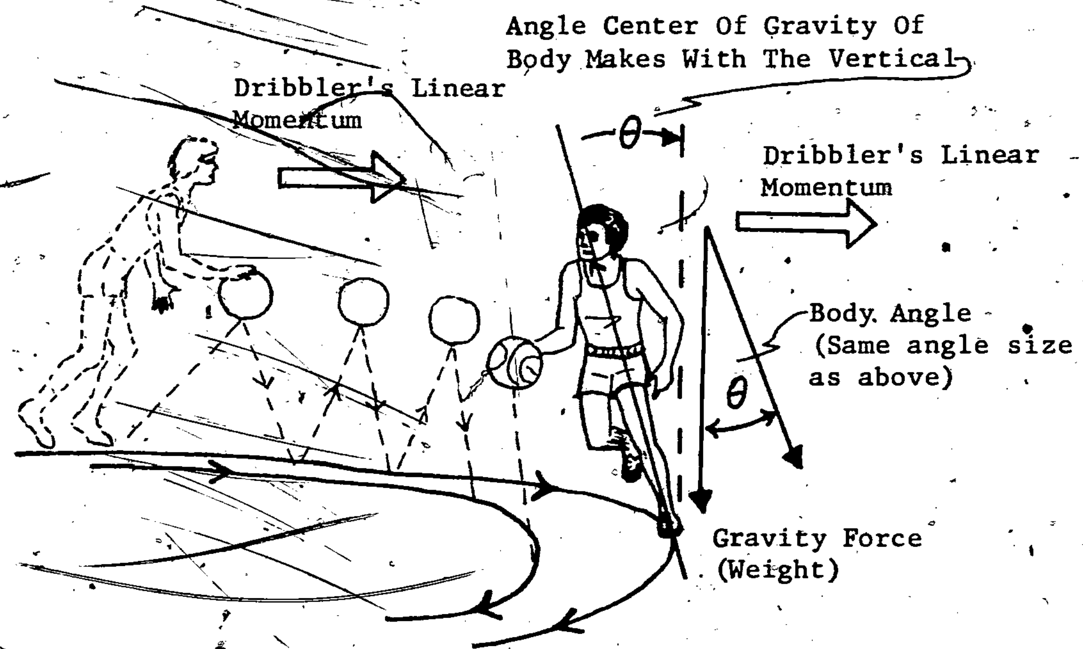


BOUNCING BALL AND SPRING ANALOG
Fig. 26

The harder the ball is thrown to the floor the greater is the reaction force (impulse), the higher the ball will bounce, and the greater will be the rebound speed.



DRIBBLING, AN EXAMPLE
OF ACTION-REACTION
Fig. 27



USING GRAVITY TO
HELP OVERCOME MOMENTUM
Fig. 28

Watch a good dribbler turn around an opponent he is trying to avoid. Notice how his body must slant toward the inside of the curve. (See Fig. 28.). The dribbler slants his body in the turn direction because the <u>inertial</u> <u>mass</u> property of his body resists change in direction from a straight line path

(1st Law). If he wishes to turn he must use force to overcome this inertia (2nd Law). By leaning, he gets force help from gravity! When he slants his body he can "fall" in the general direction he desires to move. In this way he uses the force of gravity to help overcome inertia. Of course, he uses the muscles of his legs to lean in the first place and he uses them to help him turn. He pushes harder against the floor with the foot which is on the outside of the curve. Reaction pushes him away from that direction. If you concentrate, you can hear the uneven footsteps of a runner making fast turns.

Watch a classmate dribble. Estimate the slant angles on turns. Record these. Listen for the uneven sounds of feet during turns. Record what happens to the dribbler's center of gravity when turns are made. Submit these notes for evaluation.

INVESTIGATION VII: Some Dynamics of Basketball.

Passing, dribbling, quick turn with dribble, lay-up shot, the hook shot, and the jump shot are basketball activities involving forces and the motions these forces cause. Forces and their related motions are classified in the technical physics study of dynamics.

Procedure: Ask your instructor, coach, or librarian for explanatory references on basketball techniques. Study these references. Practice dribbling (include quick turn with dribble) and practice passing and shooting (lay-up shot, set shot, hook shot, and jump shot). See Fig. 29. Record some physics principles associated with these activities and submit these for evaluation.

As the defensive player comes down the offensive player jumps up, hesitates, and makes the jump shot before the defensive player can get back up to block the shot.

THE JUMP SHOT
Fig. 29

INVESTIGATION VIII: Cycling.

Bicycling and motorcycling involve some fascinating technical physics principles and concepts. One of the reasons a rider can balance himself on a cycle is that the wheels are turning. Try balancing yourself on a motionless bicycle. What happens? For a better understanding, you could go back and read about throwing a football pass. You will find that it is the "gyroscope effect" that keeps the football on course and prevents it from tumbling end over end. The same "gyroscopic effect" allows a rider to balance a moving bicycle easily. All rotating objects tend to hold their same spinning position in space (Conservation of Angular Momentum); therefore, the spinning wheels of a cycle resist being overturned.

Suppose the cyclist starts to fall to the right. The cyclist immediately turns the front wheel to the right. The inertial property assures that motion will tend to continue in a straight line, which is to the left of where the cyclist was beginning to fall, and thus helps to place the cycle erect again. In addition, the spinning wheels provide two angular momenta axes and conservation of angular momentum tells us that each spinning wheel resists being tilted!

Work out your own investigative activity on cycling; look for examples of action-reaction, inertial moment, and angular momentum conservation. Turn your write-up in to your teacher.

INVESTIGATION IX: Swimming.

In swimming, one makes use of the action-reaction and the impulse principles by pushing against water with the arms and the legs. Also, one is buoyed up (floated) by a force explained by Archimedes' Principle. Study Archimedes' Principle in your text and in other references. Work out your own activity on swimming and turn your report in to your teacher.

OPTIONAL INVESTIGATIONS: Other good possibilities for studying physics in sports include:

a) long jump
b) high jump
c) golf
d) horseshoe pitching
e) tennis
f) diving
g) volley ball

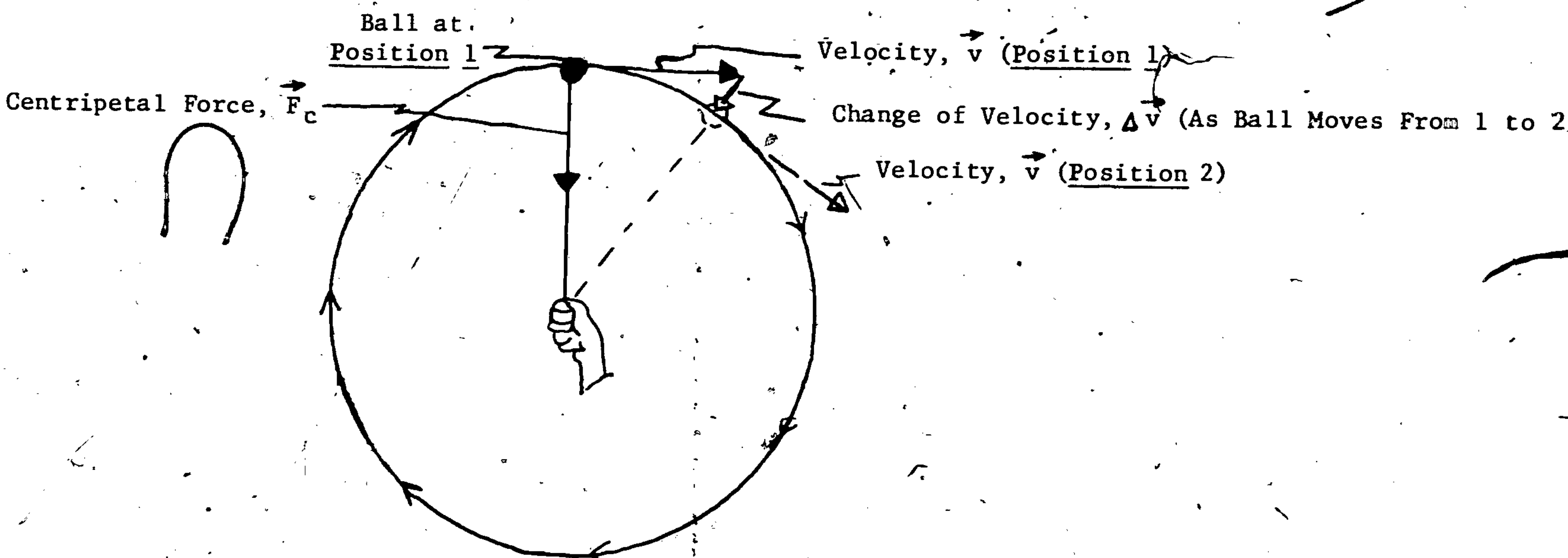
RESOURCE PACKAGE 1-9

CIRCULAR MOTION

Circular motion is a very special, yet very common kind of motion in nature. A falling leaf does not simply fall in some linear fashion, but generally rotates as it fall. Circular motion is also a very special kind of motion in sports. The football forward pass, the baseball curve, and the diver's tuck are some examples in sports where circular motion is involved.

What is so special about circular motion? For one thing, the force causing the motion (centripetal force) always acts at right angles to the motion (path) of the body at any given instant. Another special feature is that this centripetal force keeps the object moving in a circular path at constant angular speed, but does no mechanical work on the subject.

The diagram on the following page illustrates the repetitive motion of a ball moving in a circle at constant speed. The velocity vector represents the ball's instantaneous (instant to instant) linear speed and direction.



The centripetal force (central force), $\vec{F}_c$, is necessary to keep the ball in the circular orbit. With no such force (say the string breaks at position 1) the ball would move off in a straight line at constant speed forever. It would obey Newton's First Law; its initial velocity (speed and direction) would never be changed. It is the string force, $\vec{F}_c$, which accelerates the ball to curve to Position 2.

Your text probably defines linear acceleration as the measure of how linear velocity changes with time.

We can relate this linear acceleration definition to <u>angular</u> acceleration, if we are clever.

Mathematically, the linear acceleration is

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$$

Where $\Delta \vec{v}$ is some change of linear velocity

and Δt is some time change (interval).

Newton's Second Law tells us that

$$\vec{F} = m \; (\vec{a}).$$

Substituting $\frac{\Delta \vec{v}}{\Delta t}$ for a, in the equation above, we get:

$$\vec{F} = m \left(\frac{\Delta \vec{v}}{\Delta t}\right)$$

Notice in the circular motion diagram that the centripetal ("center-seeking") force $\vec{F}$ causes the <u>change</u> of the velocity vector, $\Delta \vec{v}$, <u>to be directed toward the center</u> of the circular path. Because this acceleration (change of velocity with time) is directed centrally it is given the special name <u>centripetal acceleration</u>.

It can be shown that centripetal acceleration ($\vec{a}_c$) due to the centripetal force ($\vec{F}_c$), is mathematically related to the speed (v) and to the radius of curvature (r) as follows:

$$F_c = ma_c$$
$$= m\left(\frac{v^2}{r}\right)$$

Note that since the <u>unbalanced</u> centripetal force, F_c, is directed toward the center of rotation, the centripetal acceleration, a_c, is in the <u>same</u> direction (as it must be to conform with Newton's Second Law)!

RESOURCE PACKAGE 2-1

ENERGY, POWER, AND WORK

Energy is defined as the ability to perform work. Work is defined as that which changes the energy state of a system. Power is defined as the rate of work (rate always means the time something requires).

For mechanical work to occur a force (or moment) must act through some distance. For a moment (or force) to act over a distance, energy must be expended. In athletes chemical energy is supplied by foods. The body transforms this chemical energy to muscle energy. Muscles apply forces (moments) and perform mechanical work. Some examples of work in sports would include batting a ball, swimming across a pool, running for a touchdown, smashing an overhead volley, spinning a frisbee, and blocking a basketball "lay up" shot.

In technical physics we often speak of two kinds of mechanical energies: kinetic energy and potential energy. Kinetic energy is defined as energy due to the motion of a body. Potential energy is defined as stored energy. A rock about to topple off the edge of a cliff has gravitational potential energy; as it falls its potential energy will be converted completely to kinetic energy. This conversion illustrates The Principle of Conservation of Energy, which implies that for a closed system the total energy-mass must remain fixed (be conserved).

Work can be simply expressed as the product of the force (or force component) actually moving the load and the distance over which it acts: $W = F\,d$*. $\underline{W}$ is the linear mechanical work, $\underline{F}$ is the effective force in the direction something is moved, and $\underline{d}$ is the distance over which the effective force moves the load. Also, work is: $W = M\,\theta$. $\underline{W}$ is the mechanical angular work, $\underline{M}$ is the effective twist, and $\underline{\theta}$ is the angular distance over which the moment moves the load.

Power is related to the time it takes to get the job (work) done. Mathematically, power can be expressed as:

$$P = \frac{W}{t}$$

$$= \frac{F\,(d)}{t} \quad \text{(Linear case)}$$

$$= \frac{M\,(\theta)}{t} \quad \text{(Rotational case)}$$

Consider this case: Suppose you carry two like golf bags up a flight of stairs in 30 sec, and an identical twin carries one like bag up the same stairs in 30 sec; then you have done twice as much mechanical work, you have expended twice as much energy, and you have developed twice as much power as your twin.

---

*In general, it is NOT true than "work equals force times distance". Notice that the statement reads "force (or force component) actually moving the load". If you are not clear about this implication, consult your references and then your instructor.

RESOURCE PACKAGE 2-2

STUDENT POWER!

Examples of horsepower and the related concepts of energy and work are easily recognized in sports. Let us begin by considering the activity of blocking in football.

Blocking is evidenced in the hard-hitting of offensive team players who open up a path for the ball carrier. Most of the blocking is done by guards and tackles, who are usually the strongest and most massive (heaviest) players. The backfield players (quarterback excepted) and the ends must be effective blockers, too. When two players charge into one another as in blocking, the one with greater momentum will usually win out. Since a player's momentum is a function of both his mass and his speed, a blocker needs to attain a high speed as quickly as possible. In the line, there is very little time to overcome inertia because of the closeness of the opposing players. One way a player helps himself accelerate to a high speed quickly is to dig his cleats into the ground. Cleats provide action-reaction surfaces, prevent slippage, and allow legs to exert a strong force backward; and the reaction to this force propels a player forward with increased linear momentum. Blocking involves large expenditures of energy. Because this energy is expended in a very short time, the power developed is large ($P = W/t$).

A blocker often exerts a lifting force on his opponent to upset his opponent's stability. Work is done by the blocker whenever he lifts his opponent. Again, work performed rapidly means the power developed

is higher. This "uplifting" work causes the opponent's stability base to become smaller, his center of gravity to be raised, and his center of gravity to be shifted outside the area of a stable base.

The opponent thus becomes unstable. Obviously, if the blocker has much more momentum than his opponent he can upset his opponent's stability without much lifting action. In this case, the <u>work</u> done by the blocker is less than if he lifts his opponent, but the <u>playing</u> effect is the same! . . . his opponent has been "wiped out".

Tackling is a means of stopping the player who is carrying the ball. It is difficult to tackle a good ball carrier. The tackler must first set a collision course, which necessitates estimating the runner's speed, distance, and probable future position (estimate the runner's <u>trajectory</u>). The tackle is best made low, so as to lessen momentum transfer (impact blow) and to best disrupt the ball carrier's stability. The same kinds of energy, work, and power requirements as for blocking apply.

Work is done in kicking a football, in shooting a basketball, or in pitching a baseball. The impulsive force, delivered by the foot or the hand, acts in the same direction that the ball is thrust; this <u>force</u> multiplied by the effective <u>distance</u> through which it acts is a measure of the work performed (W = F d).

Since it is difficult to isolate and to measure the amount of work performed during a game, you will be asked to conduct an investigation away from the playing field to measure power quantitatively (numerically).

Student Power (Horsepower) Investigation

Purpose: To measure the horsepower students can develop for a short time period.

Apparatus: yard stick or meter stick
stop watch or watch with sweep-second hand
scales

Procedure: Arrange the cooperation of a large male (a big football player or other athlete), a small male, and a female. Weigh each as accurately as possible. Measure the height of one of the steps of a flight of stairs. Count the number of steps in the flight. Multiply the number of steps by the height of the single step, to find the vertical height of the flight of stairs. Measure the time each student needs to run up the flight of stairs. You may wish to take an average time for two (2) or more trials. Record the data on a data sheet such as the one below (Make your own chart on a separate sheet, please. Do not mark in this minicourse.).

The amount of work each volunteer does is found by multiplying weight by the height of the flight of stairs. The power developed is the work divided by the time. To find horsepower, divide the amount of work done by the time (in seconds) times 550 ft-lb/sec/hp.

$$P(hp) = \frac{F \times D}{(550\ \text{ft-lb/sec}) \times t}$$

$$= \frac{W\ (h)}{550\ \frac{\text{ft-lb}}{\text{sec}}\ (t)}$$

SAMPLE DATA SHEET

Student Name	Trial	Weight (lb)	Height of One Step (in)	No. of Steps	Vertical Height (in)	Vertical Height (ft)	Work Done	Time	Horsepower Developed

Briefly write down responses to the following. Turn these in to your teacher, along with your data sheet.

1) What conclusions can you draw from these data? Specifically include analyses of HP/lb of student; HP/sex of student, HP/age of student.

2) Compare "student power" to a "horse's power"

3) Use a biology book and compare "student power" to that of at least one animal: hummingbird, elephant, etc.

RESOURCE PACKAGE 3-1

MACHINES (MECHANICAL AND ANATOMICAL)

Machines are used:

1) to transform energy. For example, a generator is a machine that transforms mechanical energy into electrical energy.

2) to transfer energy. For example, the drive shaft, crank shaft, connecting rod, and rear axle of a car are machines which transfer energy from the pistons in the engine to the drive wheels.

3) to multiply force. For example, a multi-speed bicycle's gears are machines which can change a small pedal force (acting through a longer distance) into a greater driving force on the rear wheel (which turns through a shorter distance).

4) to multiply speed. For example, a bicycle's gears are machines which can change a slower pedal rotation into a faster rotational motion of the rear wheel.

5) to change direction of a force. For example, the single pulley at the top of a flag pole can change a downward pulling force on the flag rope to an upward pull force on the flag. (Force direction changes, but the force size is not changed.)

You are to study these basic machines: (1) the lever, (2) the pulley, (3) the wheel-and-axle, (4) the inclined plane, (5) the wedge, (6) the screw, (7) the hydraulic piston, (8) the gear, and (9) the screw-jack. All other machines are modifications of these machines.

Mechanical advantage is a phrase which refers to the ratios of a machine's input-output forces, input-output moments, or input-output distances. Mechanical advantage is frequently categorized further as ideal or actual. The ideal mechanical advantage (IMA) assumes a theoretically frictionless condition

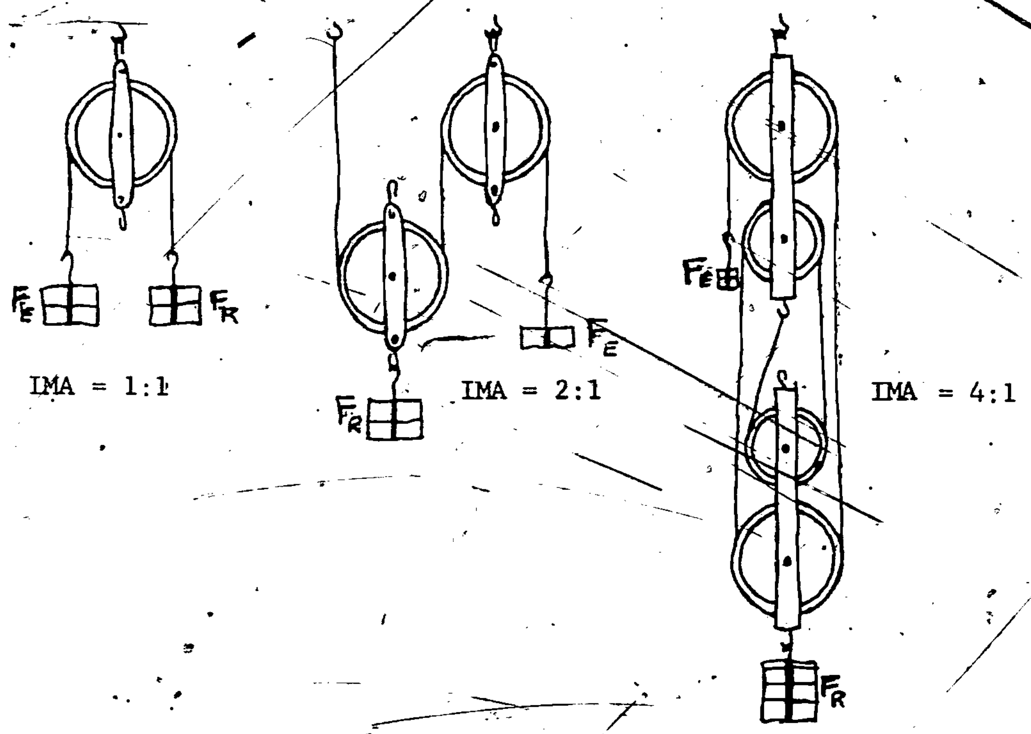
for the machine. For this reason, the IMA is also known as the theoretical mechanical advantage (TMA). One way to calculate IMA (TMA) is to divide the distance the effort force moves (D_E) by the distance the resistance force moves (D_R).

$$IMA = \frac{D_E}{D_R}$$

The actual mechanical advantage (AMA) takes into account the frictional effects of actual conditions. One way to calculate AMA is to divide the resistance force (F_R) by the effort force (F_E).

$$AMA = \frac{F_R}{F_E}$$

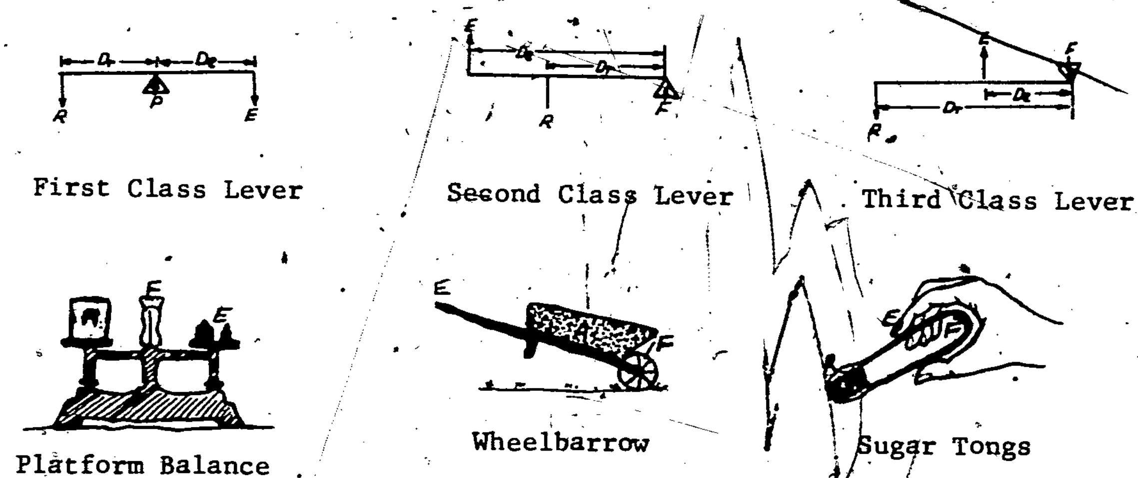
The Lever Machine. The lever machine is essentially a rigid bar free to turn about a fixed point (an axis) called the fulcrum. Levers are sometimes divided into three (3) classes, for purposes of discussion. (See Fig. 1) AMA and IMA can be found using the previous equations. In addition, the IMA can be determined from the ratio of the distances the respective forces act from the fulcrum.



SOME PULLEY SYSTEMS
Fig. 2

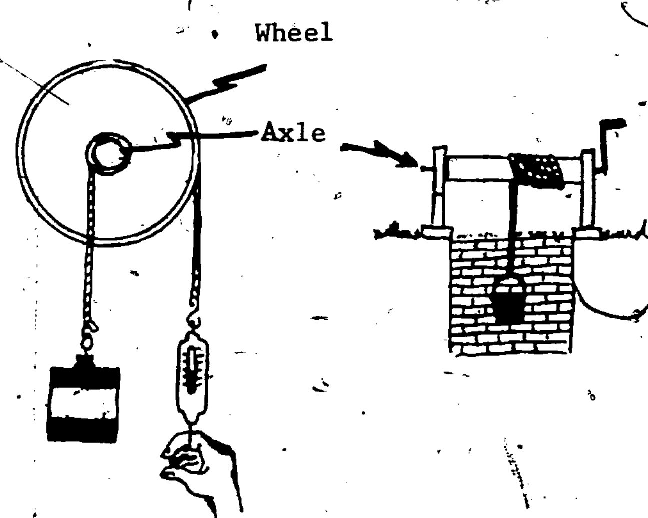
<u>The Wheel-and-Axle Machine</u>. A wheel-and-axle machine is a wheel or crank rigidly attached to an axle.

See Fig. 3.)



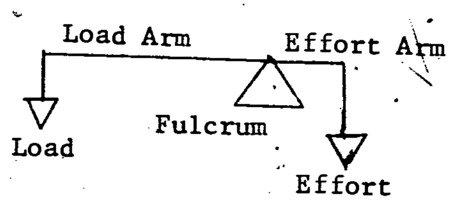
CLASSES OF LEVERS
Fig. 1

The Pulley Machine. The pulley machine is a wheel which turns on an axle mounted on a frame. Usually a belt, chain, or rope serves to transmit force to the machine. (See Fig. 2) Can you compare a simple pulley to the First Class Lever and see that they are really similar machines? (Imagine the fulcrum as the axle and the wheel rim as the end of the lever arm.) Some pulley systems are shown in Fig. 2. A pulley system's AMA and IMA can be calculated by using the previous equations.

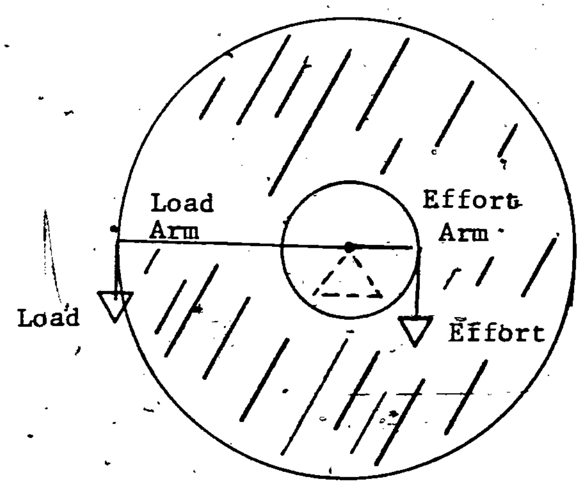


WHEEL-AND-AXLE MACHINES
Fig. 3

Can you see that the wheel-and-axle machine is simply a rotary version of the First Class Lever (as was the simple pulley.)? Notice that the wheel radius acts as <u>one arm of the lever</u>, the axle's center of rotation corresponds to the lever fulcrum, and the crank arm acts as <u>the other arm</u> of the First Class Lever. See the diagrams on next page.

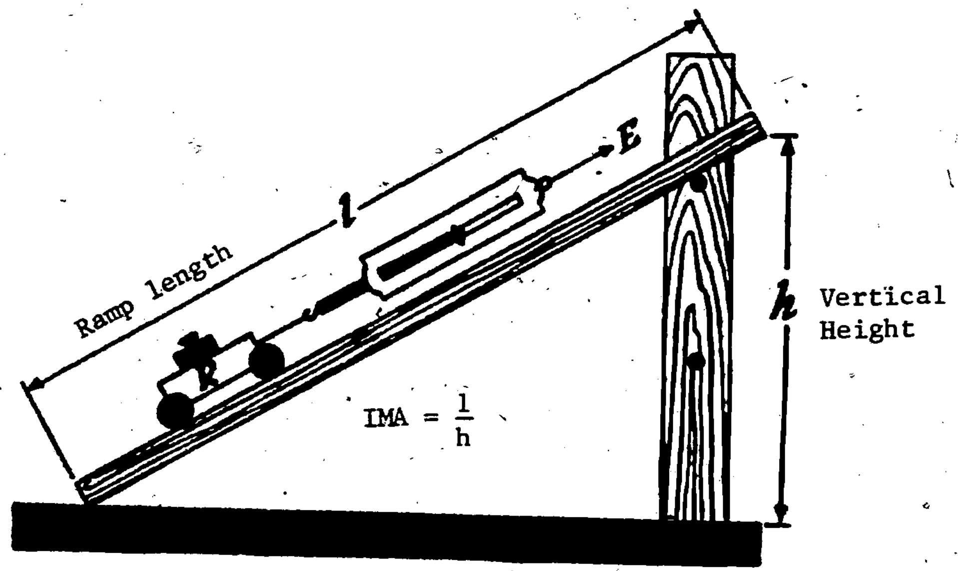


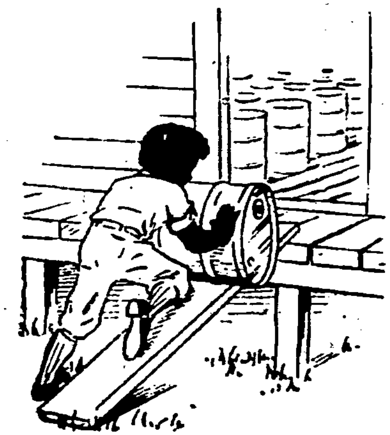
FIRST CLASS LEVER.



WHEEL-AND-AXLE.

The Inclined Plane Machine. As its name implies, this machine consists of a flat surface (plane) set at some angle (inclined) to the horizontal (See Fig. 4 on next page). A simple way to calculate the IMA of an inclined plane machine is to divide the distance of the slope (ramp length) by the vertical height.





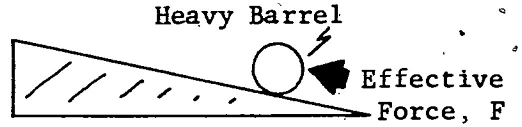
The plank enables the boy to "lift" a barrel that he could not otherwise lift.

INCLINED PLANES
Fig. 4

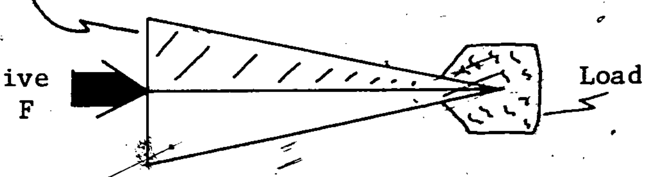
<u>The Wedge Machine</u>. Can you see that this machine is basically a double-inclined plane? (See Fig. 5 for some examples of wedge machines.)

EXAMPLES OF THE WEDGE
Fig. 5

There are two essential differences between an inclined plane machine and a wedge machine: (1) The inclined plane is stationary, while a wedge moves to do work; and (2) The inclined plane effort force acts <u>parallel</u> to the inclined plane, while the wedge's effort force acts in the <u>direction of wedge motion</u> (i.e., acts <u>normal</u> to; at right angles to; at 90° to) the trailing edge of the moving wedge. (See diagrams on next page.)



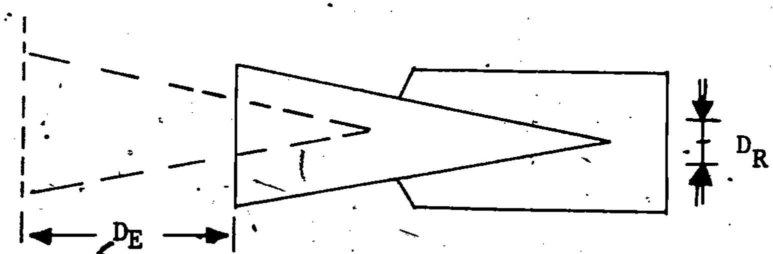
INCLINED PLANE
(Fixed loading ramp;
Effort force acts
parallel to plane.)



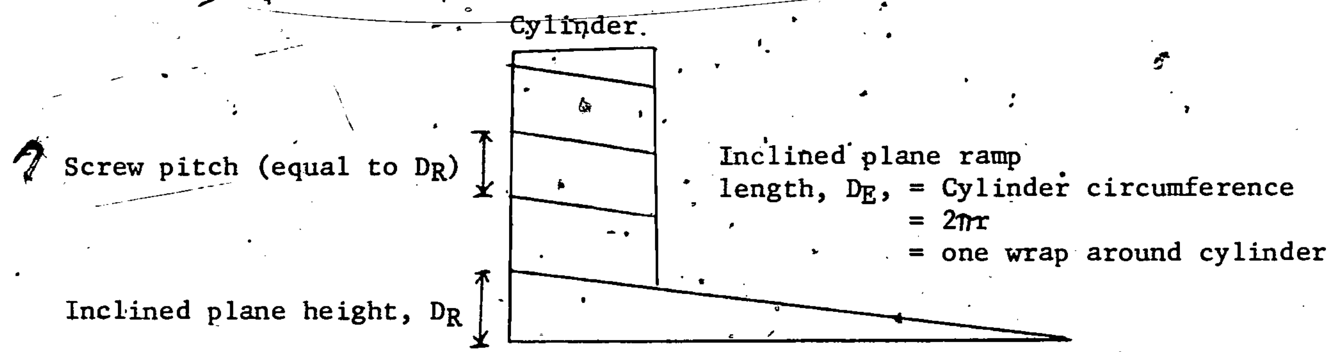
WEDGE or "DOUBLE-INCLINED PLANE":
(Movable wedge; Load is fixed;
Effort Force does not act parallel
to plane of wedge.)

Wedges are used as "holding" machines (nails, tapered fittings, etc.) and as "separating" machines (axes, chisels, double-edged knife blades, etc.). Mechanical advantage can be calculated as shown below. (Can you see that the smaller the wedge angle, the greater the mechanical advantage?)

$$IMA = \frac{D_R}{D_E}$$



The Screw Machine. The screw can be thought of as an inclined plane machine wound around a cylinder. (See diagram below.) In addition, the screw threads themselves can be designed to act as wedge machines.



Notice that the screw thread is basically an inclined plane wrapped around a cylinder. The IMA is easily calculated from the equation:

$$IMA = \frac{D_E}{D_R} = \frac{\text{one thread turn}}{\text{Screw pitch}} = \frac{2\pi r}{D_R}$$

Screw threads have many technical applications, including: (1) fastening parts (components), (2) changing circular motion to linear motion, (3) providing mechanical advantages, and (4) as adjustment or measurement devices.

The Hydraulic Piston Machine. The hydraulic piston machine differs from the others described herein because it utilizes a "working fluid" (such as oil) in its operation. The device consists basically of the working fluid, a hollow cylinder, and a piston. (See the diagram below.)

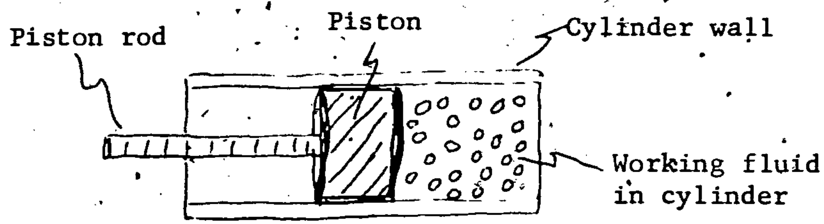
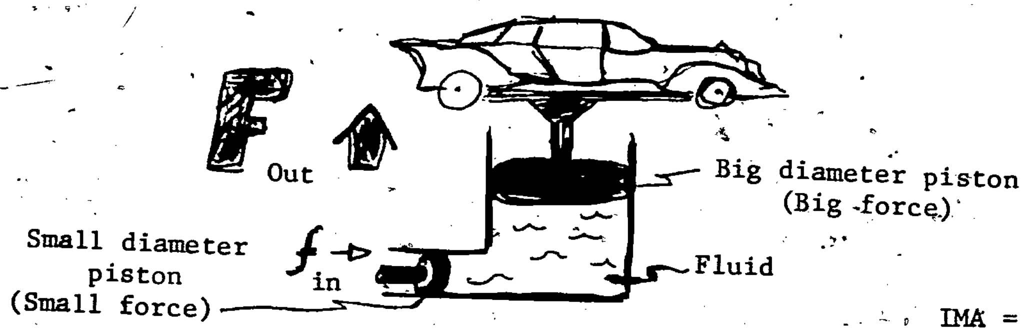


DIAGRAM OF A HYDRAULIC PISTON MACHINE

Because hydraulic pressure is the same throughout the fluid, a small piston can exert this same pressure on a larger piston sharing the fluid. Pressure is defined as force per unit area (F/A); therefore, the total force on a smaller piston (lesser cylinder head area) is less than that on a larger piston which shares the same working fluid (See Fig. 6). Since a force ratio exists, mechanical advantage results.

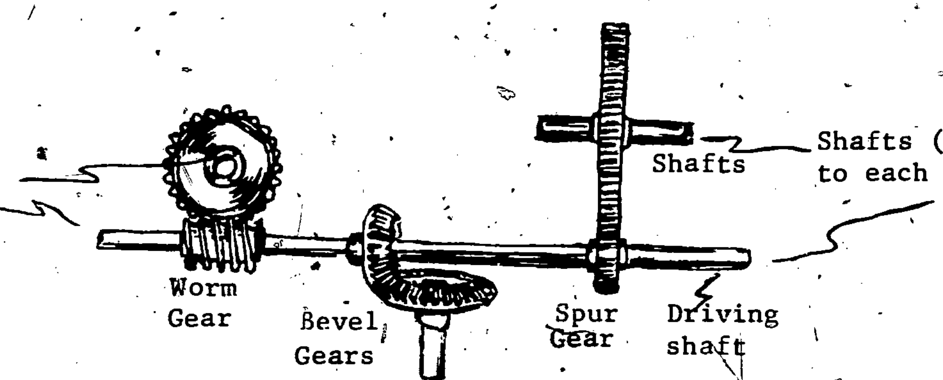


$$IMA = \frac{\text{Big piston area}}{\text{Small piston area}} = \frac{\text{Diameter (Big)}}{\text{Diameter (Small)}}$$

THE HYDRAULIC PISTON MACHINE LIFTING A CAR
Fig. 6

Can you see how the small force of a person's hand on a hydraulic jack handle can exert a force sufficient to lift a car or a house?

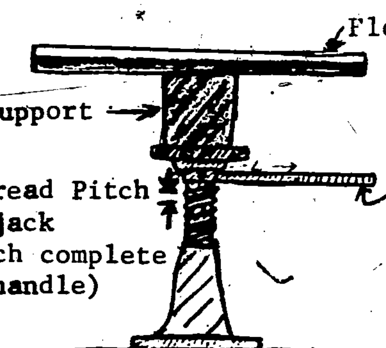
The Gear Machine. As you can see, the gear machine is a modified form of the wheel-and-axle machine. Compound machines consist of two or more simple machines in combination (compounded). A combination of gear wheels, as shown in Fig. 7, would be an example of a compound machine. Combinations of gears are called "gear trains."



Gears can be used to change speed, force, or direction.

SOME GEAR TRAINS
Fig. 7

The Screw-jack Machine. This machine is really a compound machine, consisting of a lever machine (jack handle) and an inclined plane machine wound upon a cylinder (screw machine). (See Fig. 8)



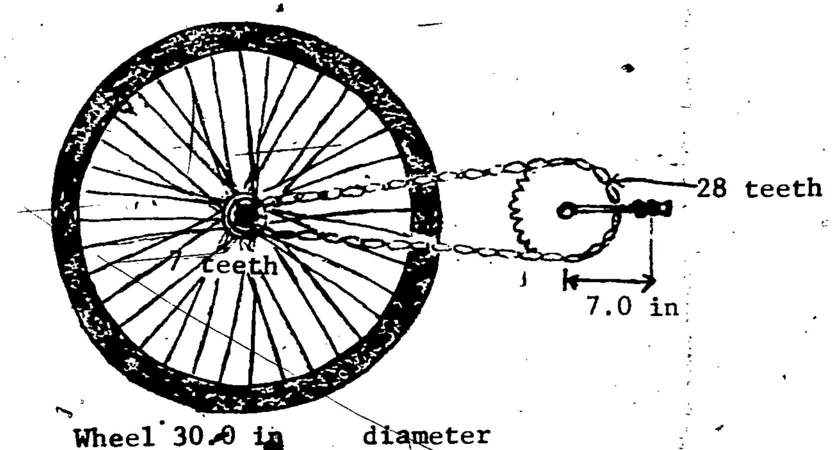
SCREW-JACK
Fig. 8

$$IMA = \frac{D_E}{D_R}$$

$$= \frac{2\pi r}{d}$$

Where D = thread pitch, or distance jack is raised each complete turn of the jack handle.

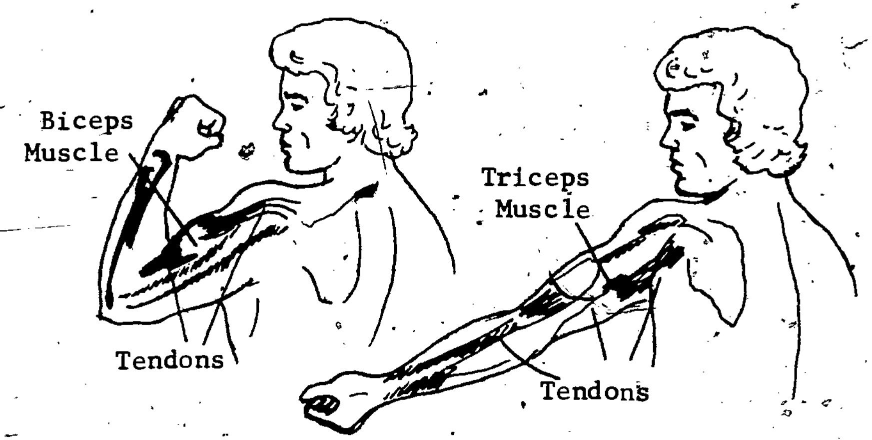
The Bicycle. Another example of a compound machine is the bicycle. The sprocket wheels are mounted on separate (axles) and are connected by a drive chain. Notice in Fig. 9 that the front sprocket wheel has 28 teeth and the rear wheel's sprocket has seven (7) teeth. Therefore, during one complete revolution of the pedals, the rear wheel must make four (4) complete revolutions. Thus, this bicycle can be said to have a mechanical advantage in terms of speed. In this example, the effort force applied to the pedal for one complete turn moves through a distance $2\pi r = 2 \times 7.0 \text{ in} \times 3.14 \cong 44$ in; and during one complete wheel turn, the rim of the rear wheel moves through a distance $2 \times 15.0 \text{ in} \times 3.14 \cong 94$ in.



TYPICAL BICYCLE WHEEL AND SPROCKETS ARRANGEMENT
Fig. 9

The Body as an Anatomical Machine. "Anatomical machine" is a phrase which refers to the machine-like functioning of the human body. Think about the body of an athlete or your own body. Each is in a sense a complicated machine capable of performing delicate skills as well as doing extremely strenuous tasks. Here are two examples of such machine-like functions:

1) As a Complex Lever Machine. Athletes exert forces through the use of muscles. These muscle forces operate the body as a lever machine. No single muscle can move any part of the body in more than one direction. Another muscle must be attached in such a way as to oppose the single muscle if direction of movement is to change. In other words, muscles have only the ability to shorten (contract) -- they cannot expand themselves. For example, to raise your lower arm the biceps muscle shortens (pulls) while your triceps muscle relaxes and gets longer. To lower the arm, the biceps muscle relaxes and gets longer while the triceps muscle shortens (pulls). Study Fig. 10 below.



BICEPS AND TRICEPS MUSCLES AND TENDONS

Fig. 10

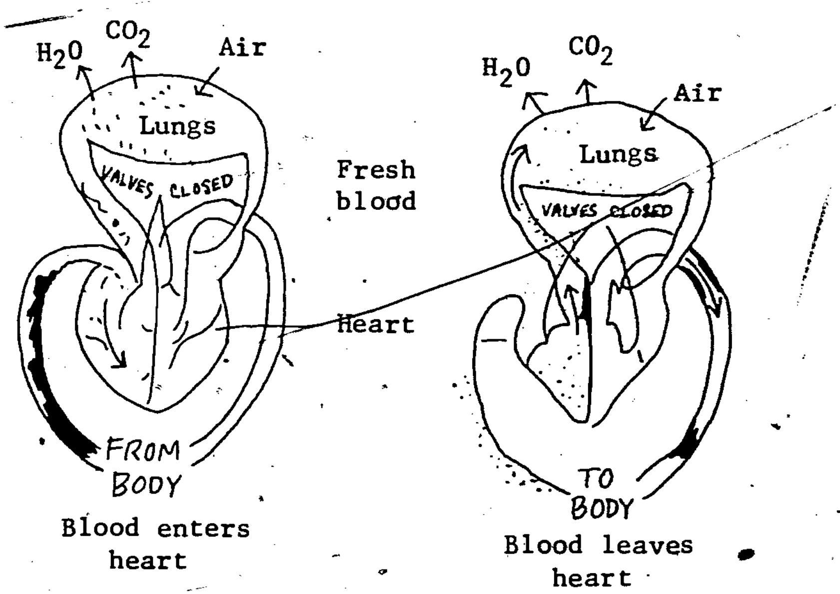
Muscles, tendons, bones, ligaments, and joints work together as complex lever machines. As mentioned, muscles can only tighten (contract) or relax; they CANNOT extend (expand) forcefully. A muscle which is able to contract (pull) in one direction can only relax to allow an opposing muscle to pull in an opposite direction. Muscles are not attached directly to bones. Muscles end in tendons which are attached to bones. When an athlete pulls a tendon, it separates the attachment to bone or muscle (See Figure 10 on previous page).

In addition to building strong muscles, athletes try to condition muscles to react quickly. They also want muscles which will work smoothly with other muscles, a basic part of what athletes call coordination. Much coordination is needed to become really skilled in any sport because a great many muscles are used in sports movements. For example, there are 150 pairs of muscles involved just in walking!

Our bodies are supported by bones, which must have joints and ligaments for mobility. These mobile joints are operated by more than 600 different muscles. Bones, muscles, ligaments (joint connectors), and joints provide for the overall mobility of the human body and serve as the components of the body's complex lever system.

2) As a Piston Pump Machine. The heart is a special kind of muscle acting as a pump (piston machine). The heart muscle pumps blood to the lungs and throughout the body. In the lungs, blood comes very close to inhaled air from which it picks up oxygen. The blood also releases body wastes (carbon dioxide and water vapor) into the lungs to be exhaled. As the blood goes through the lungs it also gives off some of the heat energy produced by the body. You can feel this heated air by "puffing" into your cupped hands. Try "puffing" right now!

During exercise, your heart muscle beats faster and pumps greater quantities of blood to the lungs and throughout the body. This is necessary because when the body is active all body cells need a greater oxygen supply and produce more chemical wastes to be carried away. (See Figure 11.)



THE HEART AS A PUMP
Fig. 11

When an athlete has just run a race or performed some strenuous activity, he has to breathe more often in order to "pay back" his body for the "oxygen debt" incurred during this strenuous exercise. For example, a 100-yard sprinter may run the <u>entire</u> race without taking a single breath because breathing interferes with the necessarily rapid coordination of the movements of his arms and legs. The athlete's heavy breathing is accompanied by an increased heartbeat rate because the heart must pump fresh oxygen-laden blood to all parts of the body.

Average heartbeat rate is 65 to 70 times a minute. Research has been done on the heartbeat rate of athletes playing basketball, tennis, football, and other active sports. The average heartbeat of these players was around 160 beats per minute. For slower sports, the rate was

lower and averaged between 126 to 152 beats per minute. After activity stops the heartbeat rate drops rapidly, but it does not reach the normal rate until about half an hour has elapsed.

Many people have the idea that an active athlete's heart always becomes permanently enlarged. This is not true, according to most doctors. The heart is able to adjust itself to changing body conditions by enlarging and diminishing in size, according to body needs. Doctors do warn people that as they grow older it is dangerous to put excessive strain on the heart, not because the heart muscle itself is generally weak but because the arteries which supply oxygen-laden blood to the heart muscle may have become clogged and/or weakened with age.

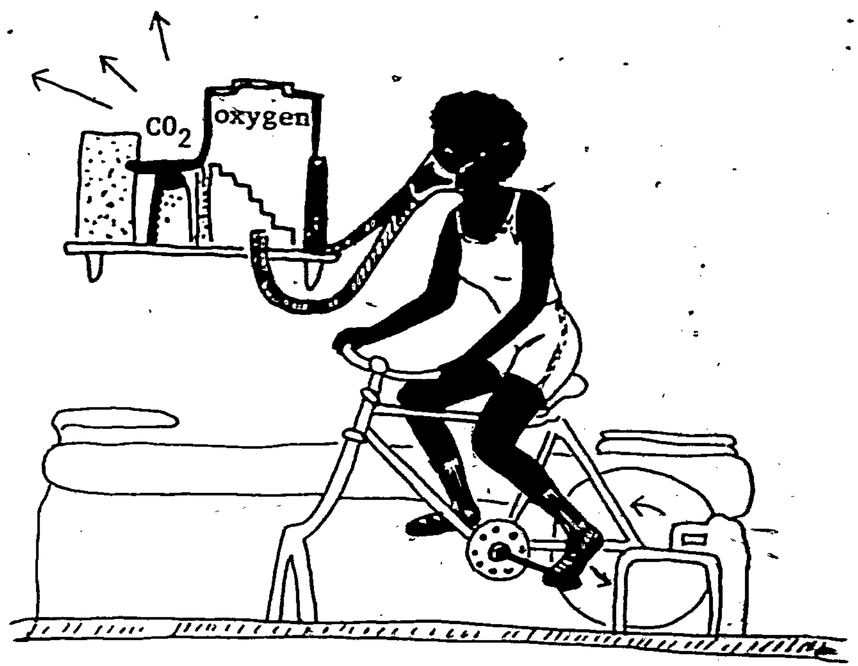
<u>The Body as a Heat Engine</u>. In addition to being compared to a machine, the body can be regarded as a heat engine. Food and oxygen are taken in as <u>fuel</u>; external <u>work</u> is done by muscular activity; and heat and carbon dioxide are <u>exhausted</u> as the principal waste products. The medical term applied to such energy transformations (heat engine-like activities) in the body is <u>metabolism</u>. While the process of metabolism is chiefly one of chemistry, a principal result is the production of heat and mechanical work. Experiments have proved that the quantities of oxygen inhaled and of carbon dioxide exhaled are directly proportional to heat production and body metabolism. One liter (≈ 1 quart) of oxygen gas will oxidize ("burn") an amount of carbohydrate, protein, or fat in the body tissues to produce 4,800 calories of heat energy.

During rest periods, when a person is motionless in a warm and comfortable environment, a steady rate of body heat production takes place. This is called <u>basal metabolism</u>, and although it varies somewhat with individuals it is used extensively in diagnosing certain ailments. Of course, when a person

is standing or working his basal metabolism rate is exceeded because his body must perform the extra mechanical work of supporting his body, of accelerating his body parts, etc.

Experiments testing the human body in terms of metabolism and the physical Law of Conservation of Energy have been made by numerous investigators. In 1895 Atwater and Benedict constructed a large heat-insulated box as a calorimeter (a heat-energy measuring device). In this box a man could sleep, eat, and ride a stationary bicycle. The energy supplied him as food was calculated from known heats of combustion of the foods. The heat energy given off by his body was removed for measurement by a stream of water.

The heat energy converted to mechanical work done when pedaling the bicycle was measured in terms of electric current produced by a generator mounted in place of the rear wheel. (See Figure 12 on next page.) The results of this experiment, carried out with twenty (20) different subjects over a period of several months, are given in the table below Figure 12. The experimental data clearly demonstrate the conformity of the human body to the Law of Conservation of Energy.



CALORIMETER
Fig. 12

	Input per day in Kilo-Calories	Output per day in Kilo-Calories	Per Cent Difference Between Input and Output
Resting	2262	2268	0.3
Working	4175	4163	0.3

DATA SUPPORTING
CONSERVATION OF ENERGY PRINCIPAL

Engine efficiency of any system can be determined from the ratio of <u>work out</u> to <u>work in</u>, with the quotient expressed as a per cent. Examine the following average energy values for ideal working conditions. They represent the highest efficiency that can be expected of the human body. What is the efficiency of the human body, as calculated from these data?

Energy required per hour of rest	100 K-Cal
Energy required per hour of work	250 K-Cal
Actual work done (in heat units)	45 K-Cal

Turn your calculations in to your teacher for evaluation.

RESOURCE PACKAGE 3-2

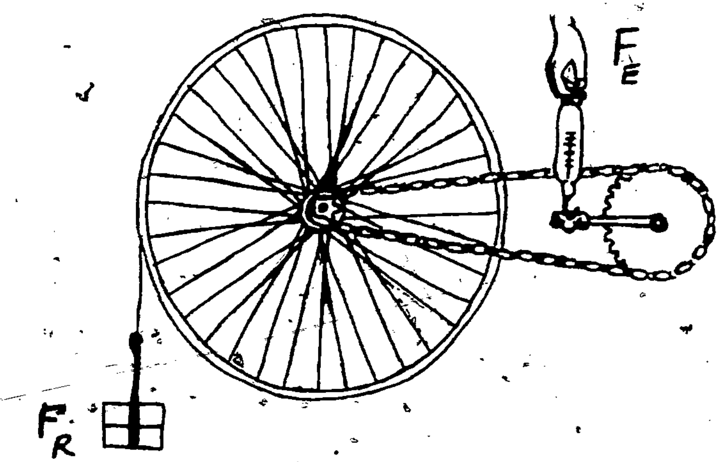
WHEEL-AND-AXLE

You will need the following items:

Bicycle
2-lb weight
Yard stick
30-lb spring balance
Support rods and clamps

Purpose: You are to investigate the machine known as the wheel-and-axle by studying a bicycle wheel and gear system. You will experimentally find its "mechanical advantage of force" and you will calculate its "mechanical advantage of speed."

Procedure: Clamp the bicycle by the frame so that the pedals and rear wheel can move freely. Look at Fig. 9.



REAR WHEEL AND PEDAL ASSEMBLY

Fig. 9

Calculate D_R (resistance force distance) for one complete turn of the pedal. Use the English system of measure. Record data in a data table of your own design. Calculate D_R. Similarly, determine D_E (effort force distance) for one complete turn of the pedals.

The distance around a circle is called its circumference, C; the distance across a circle, passing through its center, is called its diameter, D; and one-half the diameter is called the <u>radius</u>, <u>r</u>. For ANY circle, the distance around its perimeter, when divided by the greatest distance across the circle, D, <u>always yields the same number</u>. This fact puzzled the Greeks. They gave the symbol π to this <u>irrational</u> number, whose value is approximately 22/7 or 3.414. One complete turn of the bicycle pedal is a distance found from $C = 2\pi r = \pi D$.

Next fasten a 2-lb weight to the rear wheel. This will serve as the resistance force, F_R. Make sure that the weight is suspended from the rim of the wheel. See Fig. 9.

Now hook the 30-lb spring balance to the axis (center of rotation) of one pedal and pull upward. Record the reading of the spring balance when the pedal arm has been pulled to the horizontal (level) position. Record this reading as the effort force, F_E.

Now calculate the ideal mechanical advantage in terms of force in using the equation.

$$IMA = \frac{D_E}{D_R}$$

$$= \frac{\text{circumference (pedal path)}}{\text{circumference (wheel path)}}$$

("Ideal" means we ignore the effects of friction).

Next, find the actual mechanical advantage in terms of force using the equation above. In actual machines, friction forces can make a big difference! See if you notice any differences here between ideal and actual.

$$AMA = \frac{\text{Wheel Force (Resistance Force)}}{\text{Pedal Force (Effort Force)}}$$

$$= \frac{F_R}{F_E}$$

Can you find the mechanical advantage in terms of speed? Turn in your data table, your calculations, and any conclusions to your teacher for evaluation.

RESOURCE PACKAGE 4-1

SELF-TEST

I. Please write answers to the following on a separate sheet:

1) Distinguish between velocity, acceleration, and speed.

2) Using sports, give four (4) examples of (a) acceleration (b) velocity (c) speed.

3) June rolls a bowling ball down a 60-ft alley in 4.5 seconds. What is the average speed of June's ball?

4) Write down Newton's Laws of Motion.

5) Select some action in a sport to illustrate each of Newton's three laws.

6) Jean finds it easier to swim downstream (with the current) than upstream (against the current). Account for this. You may use statements or vector diagrams.

7) Annette learns that in archery, she must aim above a distant target in order to hit it. Write a short explanation of this.

8) It required the effort of Fred and two friends to start a stalled car, but Fred alone was able to keep it rolling. Write a simple explanation for this.

9) Distinguish between (a) force and work (b) work and power (c) potential and kinetic energy (e) energy and work (f) energy and power.

10) Give an example in sports where force is exerted but no work is done.

11) How does horsepower differ from power?

12) Name six (6) common devices that can be classified as machines.

13) Distinguish between "mechanical advantage of force" and "mechanical advantage of speed."

II) List some of the physics principles involved in each of the following statements, and relate each principle to the statement by using either a diagram or a brief commentary:

14) A bicycle racer leans inward when rounding a curve.

15) A pole vaulter continues to rise after releasing his pole.

16) Football players wear cleated shoes on soft turf, but gymnasium shoes serve them better on frozen turf.

17) A ping pong ball is hit so that it spins counter-clockwise around a <u>horizontal</u> axis. The ball is seen to curve <u>upward</u>.

18) A longer drive is obtained when you "follow through" in a golf stroke.

19) A "fast ball" stings the hand of the catcher more than an equally fast tennis ball.

20) A skier continues to slide downhill on an icy slope when she attempts to "snow plow."

21) A Harlem Globetrotter balances a spinning basketball on his finger tip.

RESOURCE PACKAGE 4-2

ANSWERS TO SELF TEST

1) a) Velocity is the speed of a body in a specified direction.

b) Acceleration is the rate at which velocity changes. It is the rate of "speed up", "slow down", or change of direction.

c) Speed is the rate of change of position.

2) Your answer may vary, depending on the sports and conditions. See examples in Resource Package 1-1.1.

3) Average speed, $\bar{v} = \frac{\text{distance traveled down alley}}{\text{time of travel}}$

$$= \frac{61 \text{ ft}}{4.5 \text{ sec}}$$

$$\cong 13.6 \text{ ft/sec}$$

4) See your textbook.

5) For inertia, or the First Law, you could use baseball and first base. Because of inertia, the rule book allows players to run past first base without stopping.

For acceleration, or the Second Law, you could use "following through" in golf, baseball, or similar sports. The body muscles apply forces which accelerate the club or bat. These, in turn, accelerate the ball.

For action-reaction, or the Third Law, you could use kicking a football, dribbling a basketball; etc.

6) Newton's Second Law. To find the resultant forces which will move Jean through the water, we sum forces. The two "downstream forces" (water's plus Jean's) add; but the two "upstream forces" (water's plus Jean's) act in opposite directions. The water forces must be overcome by Jean.

7) Because the pull of gravity causes the arrow to fall from the instant it leaves the bow until the instant it strikes the target.

8) It took three people to start the car moving because of inertia (1st Law). Once inertia had been overcome, Fred could pull it alone. Once rolling, the car "wanted" to keep right on rolling (because of its inertial mass property).

9) a) Force is a push or pull, while work is force times distance over which the force acts.
   b) Power is the rate of doing work ($P = \frac{W}{t}$).
   c) Potential energy is "stored" energy (static energy). Kinetic energy is "released" energy (motional energy).
   d) Energy is the ability to perform work.
   e) Energy is the ability to do work; power is the rate of work.

10) Two football blockers stopped, neither able to move the other, etc.

11) One horsepower is defined as 550 ft lb/sec. The basic unit of work in the English System is the foot-pound (ft-lb).

12) The lever, the pulley, the wheel-and-axle, the inclined plane, the screw, the wedge, etc.

13) One expresses the increase (or decrease) of force (effort), while the other expresses the decrease (or increase) of speed.

14) Centripetal force from the tire-pavement interaction.

15) Inertia.

16) Gymnasium shoes have rubber cuplets, which create a little suction and help to stabilize a person on frozen turf or a gym floor. Gym shoes also have high coefficients of friction (don't slip easily). Football cleats cannot dig into either ice or gym floors very well. Therefore, no cleat action-reaction effect can occur. Cleats have low coefficients of friction (they slip easily).

17) Bernoulli's Principle. Airstream speed is greatest on the ball's <u>topside</u>; therefore, air pressure is <u>less</u> than on the lower side and the ball must accelerate upward.

18) ~~Newton's Second Law of Motion.~~

Impulse. The driving force acts over a longer time during the "follow through".

19) It has greater momentum (mv) because its inertial mass property, m, is greater. It also has greater energy, for the same reason ($KE = \frac{1}{2} mv^2$).

20) Inertia (1st Law) and Acceleration (2nd Law). She tends to continue her slide (1st Law) and the icy snow offers little frictional force. She is being accelerated downhill by the gravity force (2nd Law).

21) Inertia (1st Law). Spinning objects tend to maintain their <u>same</u> <u>space</u> <u>positions</u> and their <u>same</u> <u>angular</u> <u>speeds</u>.